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A report is presented of a project which proposed to assemble information on exhaust gas flow rates from selected air pollution sources. The objectives of the project were: 1) to determine the extent to which operating variables and process through put rates affect exhaust gas conditions and emission rates, and 2) to recommend exhaust gas conversion factors to be used in the development of implementation plans for air quality control regions. The scope of the project required conversion factors to be developed for 76 major combustion and industrial processes. For each source category, four parameters were evaluated: gas flow rate, gas temperature, gas velocity, and stack height. The source categories are as follows: stationary fuel combustion; refuse incineration; chemical process industry; food and agricultural industry; metallurgical industry; mineral products industry; petroleum refinery; pulp and paper industry; and solvent evaporation and gasoline marketing.

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EXHAUST GASES FROM
COMBUSTION AND INDUSTRIAL PROCESSES

A Report Prepared For The
Division of Compliance
Bureau of Stationary Source Pollution Control
Office of Air Programs
U.S. Environmental Protection Agency
Technical Center
Durham, North Carolina

Contract No. EHSD 71-36

Engineering Science, Inc.
Washington, D.C.
October 2, 1971

PREFACE

This report was prepared under contract for the Office of Air Programs, Environmental Protection Agency (EPA) by Engineering-Science, Inc. to assist the federal government in carrying out its responsibilities under the Clean Air Act of 1970. Specifically, the purpose of this project was to assemble into one report information on exhaust gas flow rates from selected air pollution sources. The intention of the report was to help the EPA evaluate specific details of state implementation plans and to estimate the impact of large sources on local air quality even when details of the source were lacking. However, it is obvious to the investigators that state and local agencies also will be able to use this document as support for their emission inventory and enforcement activities.

ACKNOWLEDGMENTS

In completing this investigation, there were many people, other than the principal authors, who made significant contributions.

We wish to acknowledge the guidance and direction provided by the OAP project officers and their assistants, Messers Anthony Cortese, Ted Creekmore and Mark Harris. They were able to provide data which was not readily available from other sources and they provided help in polishing up the many draft reports.

Throughout the project, help was obtained and data was secured from several of the trade associations. The State air pollution control agencies in New Jersey, New York, Maryland, and Missouri also provided valuable data which helped make this project a success.

In Engineering-Science, Inc., M. Dean High was the principal investigator and Michael E. Lukey was project Manager. Other staff members, who worked part-time on this project, included John M. Craig, Ph.D., Gary Thom, J.K. Allison, Terrence A. LiPuma, and Franklin Meadows.

The typing of this report was completed by Mrs. Linda Arrasmith, whose diligence was especially appreciated.

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CHAPTER I

INTRODUCTION AND SUMMARY

The objectives of this project were:

1. To determine the extent to which operating variables and process throughput rates affect exhaust gas conditions and emission rates.
2. To recommend exhaust gas conversion factors to be used in the development of implementation plans for air quality control regions.

The scope of the project required conversion factors to be developed for 76 major combustion and industrial processes suggested by the Office of Air Programs. For each source category, four parameters were evaluated: gas flow rate, gas temperature, gas velocity, and stack height. In addition, a brief description of the industry, its operating characteristics, including an input - output relation, and a process description were provided.

A linear regression and the statistical confidence of the conversion factors were included where sufficient data existed (more than 6 points) Also, the reliability or credibility of the conversion factors for each source category was rated from A to E with "A" considered good, "C" average, and "E" poor. To be considered good a source category had to have numerous exhaust gas field measurements covering all important operating variables.

The project did not involve any field measurements. Nor did it include review or update of air contaminant emission factors, i.e., the emission rate of dusts, sulfur oxides, etc. Also, the use of control equipment by each source category was indicated in the discussion. However, collection efficiencies of the devices for each process within the categories were not reviewed or tabulated. An earlier document of OAP entitled "Air Pollutant Emission Factors" (August 1970) does contain both types of information. If such information is not available, however, the following general collection efficiencies might be assumed:

Particulates	
Baghouse	99%
Electrostatic precipitators	90%
High energy scrubbers	90%
Low energy scrubbers	75%
Mechanical collectors (cyclones & dry collectors)	50%

Organic Gases	
Afterburners	99%
Adsorption	90%
Inorganic Gases	
Scrubbers	75%

Information presented in this report was obtained primarily from published technical literature, from Federal, state and local air pollution control agency files, from conferences with trade association, and from the experience of the Engineering-Science, Inc. staff members.

Several abbreviations and equations were shortened specifically for the summary table. A brief discussion of each of the factors follows to facilitate their usage. The flow rate is always given in terms of scfm (70°F and 1 atm.) and is given as a function of an input or an output rate. In the case for anthracite coal combustion the flow rate is based on the coal feed rate, in pounds per hour. For bituminous coal fired power plants the flow rate is also based on the megawatts of power generated,an output parameter. In several instances a functional relationship for the flow rate could not be established, therefore a mean and range are offered for those sources. (This is mainly due to the scatter in the data when the flow rate was plotted with the input/output factor.) For example, under the source category "Domestic Incineration" the flow rate is listed as 35 scfm. The range for these units is 4 to 51 scfm. The exhaust gas temperature is the temperature of the gases at the exit point. Temperature is given in Farenheit and Centigrade units. The velocity indicated in the summary table is the actual exit velocity given in feet per second and meters per second. The stack height is given in feet and meters. Under the column Common Control Device, we have listed abatement equipment commonly used for the specific category. (A list of their collection efficiencies has been discussed above.) In several instances more than one control device was common. In those cases we have given two flow rates, termperatures, velocities, etc., but only where these different control devices changed the conversion factors. "None" means that no control equipment is commonly used. In the column labled Other Data, additional information was listed about a specific source. Excess air rates are given for combustion and incineration catagories because they are important parameters which effect exhaust gas flows. For industrial catagories process weight ranges and operating times are included in the "Other Data" Column.

Throughout this report the flow rates are given in standard cubic feet per minute. An attempt was made initially to report both actual and standard flow rate equations. However there was a general lack of correlation of actual flows with the input-output parameter because of the fluctuation in gas temperature for the data. To correct the flow from standard conditions to actual conditions, the following equation is used:

$$Q \text{ actual} = \frac{(460 + T_s)\ Q \text{ std.}}{530^{\circ}}$$

Q actual = Flow Rate at actual conditions
T_s = Actual stack gas temperature (°F)
Q std = Flow Rate at Standard Conditions (70° and 1 atm)

(The equation assumes no change in pressure for standard to actural conditions)

The bulk of the time spent on this project was utilized in obtaining the data. A prodigious amount of data is available for these categories on emission rates: however, many literature sources did not include flow rates, gas temperatures, velocities, stack heights, or input-output characteristics. In those instances estimates were made for these parameters. The estimates were based on our prior experience, theoretical calculations, safety factors (for aerodynamic fatigue velocities) and other consultants experience.

Caution should be exercised in applying the conversion factors to a specific plant or process. The factors should be used as a first pass or rough approximation of exhaust gased but detailed source data should be used to verify and refine the estimate whenever possibe. Furthermore, for a few industrial processes, no data were found to even begin to estimate exhaust emissions. It is suggested that investigators in the field consistently report gas flow rates and conditions. Finally, this type of investigation should be updated and expanded at some later date to improve upon the value of such conversion factors

A summary table of all conversion factors and exhaust gas conditions is presented for easy and quick reference by the reader. For backup or explanation, please refer to the appropriate chapter in the discussion.

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature ^{o}F	^{o}C	Velocity fps	mps	Stack Height ft.	m.		
II	COMBUSTION									
II-1	ANTHRACITE COAL	coal feed 3.3 x lb/hr	450	232	25	7.6	60	18.3	Mechanicals	50% Excess Air
II-2	BITUMINOUS COAL power plants	2430 x mw + 81900 7000 x feed rate ton/hr.	280	138	50	15.2	300	91.4	Precipitator	12-25% Excess Air
II-2	BITUMINOUS COAL industrial/commercial	coal feed 3.15 x lb/hr + 210	500	260	30	9.1	60	18.3	Mechanicals	50% Excess Air
II-3	RESIDUAL FUEL OIL power plants	oil feed 27.2 x gal/hr - 570	300	149	40	12.2	200	61.0	Mechanicals	20% Excess Air
II-3	RESIDUAL FUEL OIL industrial/commercial	oil feed .05 x gal/hr	500	260	30	9.1	60	18.3	None	60% Excess Air
II-4	DISTILLATE FUEL OIL	oil feed 43 x gal/hr + 590	350	177	20	6.1	35	10.7	None	65% Excess Air
II-5	NATURAL GAS power plants	gas feed 201060x(10^{6}cfh) - 8600	310	154	50	15.2	300	91.4	None	10% Excess Air
II-6	LIQUEFIED PETROLEUM GAS	same as natural gas								
II-7	WOOD WASTE	wood feed 210x(10^{6}BTU/hr)+36400	500	260	30	9.1	250	76.2	Mechanicals	50% Excess Air

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit								
Chapter	Description	Flow Rate scfm	Temperature ^{o}F	^{o}C	Velocity fps	mps	Stack Height ft.	m.	Common Control Device	Other Data
III	INCINERATION									
III-1	MUNICIPAL	refuse feed 3070 x ton/hr + 16200	500 800	260 427	25	7.6	150	45.7	Water cooled None	200% Excess Air
III-2	INDUSTRIAL/COMMERCIAL	refuse feed 3070 x ton/hr + 16200	1200	649	20	6.1	40	12.2	None	100% Excess Air
III-3	DOMESTIC flue-fed	refuse feed 3.22 x lb/hr + 414	700 1200	371 649	20	6.1	35	10.7	None Afterburner	200% Excess Air
III-3	DOMESTIC controlled air	heat input 400 x (10^{6}BTU/hr)	1000	537	30	9.1	25	7.6	None	200% Excess Air
III-3	DOMESTIC home	35 (4-51)	500	260	9	2.7	15	4.6	Afterburner	400% Excess Air
III-4	PATHOLOGICAL	refuse feed 5 x lb/hr	1000	537	15	4.6	50	15.2	Afterburner	100% Excess Air
III-5	AUTO BODY	3000 (2000-5000)	1100	593	30	9.1	50	15.2	Afterburner	100% Excess Air
III-6	CONICAL BURNER	feed rate 7 x lb/hr	400	204	15	4.6	60	18.3	None	1000% Excess Air
III-7	OPEN BURNING	feed rate 20 x lb/hr	150	66	2	0.6	0	0	None	5000% Excess Air

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
IV	CHEMICAL PROCESSES									
IV-1	AMMONIA	nat. gas feed .222 x cfh	950	510	50	15.2	100	30.5	None	400-600 tpd cont.
IV-2	CARBON BLACK furnace black	nat. gas feed 0.012 x cfh	500	260	40	12.2	150	45.7	Precipitator	cont.
IV-2	CARBON BLACK channel black	nat. gas feed .1 x cfh	500	260	10	3.0	20	6.1	None	cont.
IV-3	CHARCOAL all stacks, one kiln	1200 (800-2000)	500	260	10	3.0	15	4.6	None	Avg. 50 cords 7 days of 25
IV-4	CHLORINE entire plant	600 (8-1078)	60	16	10	3.0	50	15.2	None	50-500 tpd cont.
IV-5	HYDROFLUORIC ACID vents kiln	1000 (15-3000) 5000 (3000-8000)	120	49	10	3.0	50	15.2	Scrubber	275-1000 tpd cont.
IV-6	NITRIC ACID	prod. rate 3.16 x lb/hr + 700	450 80	232 27	50	15.2	200	61.0	Afterburner Scrubber	50-750 tpd cont.
IV-7	PAINT AND VARNISH mixers	mixer cap. 6.0 x gal/hr	60		15	4.6	40	12.2	Scrubber	50-500 gph 7.5 hrs/cycle
IV-7	kettles	kettle cap. 0.5 x gal/hr	140 1150	60 621	15	4.6	40	12.2	None Afterburner	8.6 hrs/cycle
IV-8	PHOSPHORIC ACID wet process	plant cap. 60.0 x ton/day	100	38	30	9.1	50	15,2	Scrubber	100-1100 tpd cont.

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
IV-8	thermal process	P_4 feed rate 2.16 x lb/hr + 1190	170	77	30	9.1	50	15.2	Scrubber	50-500 tpd cont.
IV-9	PHTHALIC ANHYDRIDE	9.0 x feed rate lb/hr 50 (20-67)	140	60	35 5	10.7 1.5	70 30	21.3 9.1	Scrubber None	40-175 tpd cont.
IV-10	PLASTICS total plant (poly, vessel, reat , vents)	5000 (50 - 8000)	100 1000	38 538	10 35	3.0 10.7	60	18.3	None Afterburner	800-40000 lb/hr cont.
IV-11	PRINTING INK loading of mixer	5000 (2000-10000) 10 mins. intermittent	60	16	35	10.7	30	9.1	Scrubbers	2sh , 5 dpw
IV-12	SOAP AND DETERGENTS Detergents -- dryer	40000 (14000-66000)	120	49	100	30.5	50	15.2	Cyclones Scrubbers	
IV-12	Soap entire plant	5000 (3000-10000)	60	16	35	10.7	50	15.2	Scrubbers Afterburners	
IV-13	SULFURIC ACID w/o mist collectors	0.074 x prod. rate tons/day - 3000	160	71	30	9.1	150	45.7	Absorber Scrubber	100-1000 tpd cont.
IV-13	w/mist collectors	0.062 x prod. rate tons/day	160	71	30	9.1	150	45.7	Abosrber	100-1000 tpd cont.
IV-14	SYNTHETIC FIBER autoclave/evaporator	2400 (1000-4000) 5 second intermittent discharge	500	260	200	61.0	75	22.9	None	60-500 tpd cont.
IV-15	SYNTHETIC RUBBER fluidizing, polymerization	2000 (1600-2850)	100	38	50	15.2	75	22.9	Mechanical	Avg 200000 lb/bat cont.

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
V	FOOD AND AGRICULTURAL									
V-1	ALFALFA DEHYDRATING rotary dryer plus hammermill	prod. rate 6.8 x lb/hr	120	49	10	3.0	30	9.1	Mechanical	2000-5000 lb/hr - cont.
V-2	COFFEE ROASTING roaster	prod rate 0.40 x lb/hr cont. 0.67 x lb/hr batch	800	427	20	6.1	35	10.7	Afterburner	3000-10000 lb/hr cont. 300-1200 lb/bat. 15 min/bat
V-2	stoner cooler	40 x .140 x lb/hr 120 x .200 x lb/hr	60 200	16 93	20	6.1	35	10.7	Mechanical	-
V-3	COTTON GIN dryer	3000 x bale/hr	100	38	10	3.0	30	9.1	Mechanical	12-15 bales/hr cont. in season
V-4	FEED AND GRAIN grain cleaner and hammermill	grain processed 2.5 x lb/hr	60	16	10	3.0	150	45.7	Mechanical	cont.
V-5	FISH MEAL driers	fish meal processed 2.5 x lb/hr	150	66	10	3.0	30	9.1	Mechanical	20000-40000 lb/hr 2sh, 5 dpw
V-6	FERMENTATION fermenter vent	20 (10-500)	85	29	3	0.9	50	15.2	Afterburner	cont.
V-7	MEAT SMOKEHOUSES	4 x sq ft floor area			5	1.5	30	9.1	Afterburner	cont.
V-8	STARCH MANUFACTURING dryer	starch processed 2.0 x lb/hr	140	60	60	18.3	75		Mechanical	Avg. 20000 lb/hr 6-7 dpw

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
VI	METALLURGICAL INDUSTRY									
VI-1	PRIMARY ALUMINUM vertical prebaked and horizonal	500 (300 - 600) 2500 (1800 - 3500)	300	149	30	9.1	200	61.0	Precipitator	220-750 tpd cont.
VI-2	PRIMARY COPPER roaster	0.70 x prod. rate lb/hr+3400	350	177	35	10.7	300	91.4	Precipitator Acid plant	3000-36000 lb/hr cont.
VI-2	reverb converter	1.41 x lb/hr+3400 0.70 x lb/hr+20000	350	177	35	10.7	300	91.4	Precipitator	
VI-3	STEEL MILL sintering plant	2.0 x prod. rate lb/hr	300 150	149 66	35	10.7	150	45.7	Mechanical Scrubber	2000-6000 tpd cont.
VI-3	blast furnace	0.5 x lb/hr	350	177	35	10.7	150	45.7	Mechanical	
VI-3	open hearth	1130 x ton/hr + 11400	200	93	35	10.7	200	61.0	Flues Precipitator	12 hr heat
VI-3	BOF furnace	875 x ton/heat	300	149	35	10.7	200	61.0	Precipitator Scrubber	
VI-3	electric furnace	630 x ton/heat + 10700	150	66	35	10.7	200	61.0	Baghouse Scrubber	
VI-4	PRIMARY LEAD sintering plant	1.1 x prod. rate lb/hr	135	57	35	10.7	200	61.0	Baghouse Precipitator	13000-45000 lb/hr cont.
VI-4	blast furnace	.6 x lb/hr	225	107	35	10.7	200	61.0	Baghouse Precipitator	

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit									
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.	Common Control Device	Other Data
VI-4	reverberatory furnace	.3 x 1000 lb/hr	225	107	35	10.7	200	61.0	Baghouse Precipitator	
VI-5	PRIMARY ZINC roaster	prod. rate 1.2 x lb/hr	300	149	35	10.7	200	61.0	Precipitator Acid plants	120-700 tpd cont.
VI-5	sintering machine	1.2 x lb/hr	200	93	35	10.7	200	61.0	Cyclones	
VI-5	distillation furnace	25 x lb/hr	160	71	35	10.7	200	61.0	Baghouse	
VI-6	METALLURGICAL COKE	10/lb coke prod.	550	288	10	3.0	20	6.0	None	cont.
VI-7	SECONDARY ALUMINUM	prod. rate 1.0 x lb/hr	500 200	260 93	20	6.1	40	12.2	None Scrubber	50-500 tpd tpd
VI-8	SECONDARY BRASS AND BRONZE	prod. rate 10 x lb/hr	200	93	50	15.2	30	9.1	Baghouse	2sh, 5 dpw
VI-9	GRAY IRON FOUNDRY	prod. rate 1.0 x lb/hr	200	93	40	12.2	75	22.9	Scrubbers	3-11 tons/hr 2sh, 5 dpw
VI-10	SECONDARY LEAD blast furnace	prod. rate 3.0 x lb/hr	200	93	50	15.2	100	30.5	Baghouse	Avg. 25 tpd 2sh, 5 dpw
VI-10	reverberatory	3.0 x lb/hr	200	93	50	15.2	100	30.5	Baghouse	
VI-10	pot furnace	3 x lb/hr	200	93	50	15.2	100	30.5	Baghouse	

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
VI-11	SECONDARY MAGNESIUM each pot	1200 (900-1500)	320	160	10	3.0	10	3.0	None	cont.
VI-11	SECONDARY MAGNESIUM total plant	prod. rate 22 x lb/hr	90	32	20	6.1	65	19.8	None	cont.
VI-12	STEEL FOUNDRY	prod. rate 3.3 x lb/hr	150	66	50	15.2	75	22.9	Scrubber	25-240 tpd cont.
VI-13	SECONDARY ZINC	prod. rate 1.0 x lb/hr	150	66	35	10.7	40	12.2	Baghouse	-

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
VII	MINERAL PRODUCTS									
VII-1	ASPHALT ROOFING felt saturator	1000 (100-1050) 15000 (10000-20000)	230 110	110 43	4 40	12.2	60 60	18.3 18.3	None Scrubber	1-15 tph 2sh, 5 dpw
VII-2	ASPHALT dryer kiln	prod. rate 53 x tons/hr. + 12600	225 100	107 38	10 10	3.0 3.0	30 30	9.1 9.1	Mechanical Scrubber	50-200 tph 1 sh, 5dpw
VII-3	BRICKS AND CLAY screening kiln	15,000 (500-30000) 1,500 (1000-2500)	60 200	16 93	10 10	3.0 3.0	30 15	9.1 4.6	Baghouse None	Avg. 100 million bricks per year 1 sh, 5dpw
VII-4	CALCIUM CARBIDE furnace	250000 (152000-368000)	150	66	50	15.2	80	24.4	Scrubber	Avg. 200 tpd cont.
VII-5	CASTABLE REFRACTORY dryer	7500 (1000-14000)	500	260	35	10.7	30	9.1	Baghouse	30-50 tpd 2sh, 5 dpw
VII-6	CEMENT Wet process Dry process	prod. rate .71 x lb/hr + 40200 .61 x lb/hr + 16500	400 550	204 288	40	12.2	200	61.0	Baghouse	10000-500000 lb/hr cont.
VII-7	CERAMIC CLAY Mixer Drier	4000 (400-21000)	60 200	16 93	50	15.2	30	9.1	Mechanicals	30-3000 lb/hr 2sh, 5dpw
VII-8	CLAY AND FLY ASH sintering	20000 (10000-20000)	450	232	30	9.1	150	45.7	Precipitator	Avg. 200 tph cont.
VII-9	CONCRETE BATCHING material transport	300 (200-500) 5000 (2000-7000)	60	16	5 20	1.5 6.1	35	10.7	None Baghouse	1 sh, 5dpw

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
VII-10	FIBER GLASS forming and curing	20000 (400-65000)	200	93	40	12.2	60	18.3	Mechanical Afterburner	50-500 lb/hr cont.
VII-11	GYPSUM drying kiln	40000 (3900-48500)	150	66	50	15.2	75	22.9	Scrubber	Avg. 500 tpd 2sh, 5 dpw
VII-12	LIME kiln	40000 (19000-62000)	170	77	35	10.7	300	91.4	Scrubber	50-650 tpd cont.
VII-13	PERLITE furnace	5000 (3500-6400)	200	93	40	12.2	50	15.2	Mechanical	Avg 2000 lbs/hr cont. 5dpw
VII-14	MINERAL WOOL cupola blow chamber	4600 (4550-4760) 20000 (11100-28000)	300 200	149 93	25	7.6	50	15.2	Baghouse	Avg. 50 tpd cont.
VII-14	curing oven coolers	5000 (1640-8000) 9000 (1850-11350)	300 200	149 200	25	7.6	50	15.2	Afterburner	
VII-15	ROCK AND GRAVEL crusher	prod. rate 600 x ton/hr	60	16	5 30	1.5 9.1	30	9.1	None Baghouse	Avg. 100 tpd 1 sh 5pdw
VII-16	GLASS PLANT	10000 (5000-15000 transport system 1200 (800-1600) forming machine	60 100	16 38	25 2	8.2 .6	60 20	18.3 6.2	Mechanical & Baghouse None	cont.
VII-17	FRIT PLANT smelter	400 (1000-5000)	600		40		40	12.2	Baghouse or Scrubber	100-1500 lb/hr cont.

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Height ft.	m.		
VIII	PETROLEUM REFINERY									
VIII-1	Catalyst regenerators	2.0 x oil feed rate bbl/day	650	343	30	9.1	150	45.7	Precipitator	5000-50000 bpd cont.

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
IX	PULP MILL									
IX-1	KRAFT recover furnace	pulp prod. 189 x ton/day	350 170	177 77	30	9.1	250	76.2	precipitator scrubber	Avg. 10000 tpd cont.
IX-1	lime kiln	pulp prod. 26 x ton/day	180	82	20	6.1	30	9.1	scrubber	
IX-1	digester relief and blow tank	pulp prod. 0.10 x ton/day cont. 0.20 x ton/day batch	120	49	20	6.1	30	9.1		
IX-1	dissolving tank	pulp prod. 40 x ton/day	200 160	93 71	20	6.1	30	9.1	none scrubber	
IX-2	SULFITE recovery furnace	pulp prod. 208 x ton/day	165	74	20	6.1	200	61.0	precipitator	Avg. 10000 tpd cont.
IX-2	digester relief and blow tank	pulp prod. .30 x ton/day	180	82	20	6.1	30	9.1	-	
IX-3	NEUTRAL (NSSC) recovery furnace	pulp prod. 15.6 x ton/day	325	163	20	6.1	200	61.0	precipitator	Avg. 10000 tpd cont.
IX-3	blow tank	pulp prod. 16.5 x ton/day	200	93	20	6.1	30	9.1		
IX-3	absorption tower	pulp prod. 2.4 x ton/day	100	38	20	6.1	30	9.1		
IX-3	fluidized bed reactor	pulp prod. 85 x ton/day	180	82	20	6.1	30	9.1		

SUMMARY TABLE

EXHAUST GASES FROM COMBUSTION AND INDUSTRIAL PROCESSES

Source Category		Exhaust Gases At Stack Exit							Common Control Device	Other Data
Chapter	Description	Flow Rate scfm	Temperature °F	°C	Velocity fps	mps	Stack Height ft.	m.		
X-1	DRY CLEANING	7500 (5000-10000)	100 700	38	10 40	3.0 12.2	30	9.1	None Afterburner	Avg. 500 lb/day 8 hr/day, 5dpw
X-2	SURFACE COATING hood exhaust	12000 (600-60000) 5000 (2000-6000)	60 700	15 371	40	12.2	50	15.2	Afterburner	cont. 5dpw
X-3	GASOLINE MARKETING	-	60	15	5	1.5	20	6.1	None	intermittent

CHAPTER II-1

ANTHRACITE COAL COMBUSTION[B]

Anthracite coal production and use is centered in Pennsylvania where this "hard" coal is burned primarily in space heaters and small industrial/commercial boilers, such as apartment houses, schools, municipal buildings, small office and commercial structures and small industries requiring process steam. The most numerous anthracite users are small domestic units which burn from 15 to 50 pounds per hour. Small industrial/commercial units, with ratings up to 10 million BTU/hr, burn 100 to 1,000 pounds per hour. Pennsylvania Power and Light Company reportedly is the only electric utility in the Nation that has anthracite coal-fired generating units.[1]

Anthracite heat values range from 11,500 to 14,000 BTU/lb. with a mean of about 12,500 BTU/lb.[2] Typical analyses for anthracite (Table II-1.1) will show it to have lower sulfur, volatile matter, and ash but higher fixed carbon than bituminous coal.

Anthracite furnace use and operation follow the degree-day curve since demand for space heat has wide variations caused primarily by variations in the ambient air temperature. When no degree day-curve is available, assume 12 hours per day operating time. On the average, most units run at about 60% of their designed capacity with peak load periods running up to 130% of design capacity. An abundance of data were available for analyzing boiler output and fuel feed rates[3,4] (Figure II-1.1). The data were plotted at the actual operating loads which ranged from 20 to 136% of the manufacturers' design capacities. From this curve, the efficiency of the operating units appears to average about 70% (output-BTU/hr./input-BTU/hr.); this efficiency should be used in calculations unless more specific information is available. Over 30 data points provided an average heat efficiency of 70%; the complete list is shown in Table II-1.2. Mechanical collectors are sometimes used to control fly ash emissions, but they have no influence on exhaust flow rates and very little on temperature or velocity of the combustion gases.

GAS FLOW RATE

Excess air rates ranged from 18 to 200%, but most furnaces operate between 50 and 100% excess air (Table II-1.2). Such wide variations in excess air rates are typical among small domestic and industrial fired boilers. From this data, larger units appear to operate with somewhat less excess air than smaller units. Generally though, exhaust gas flow rates will total between 300 scfm and 450 scfm per 100 pounds/hour of coal burned (Figure II-1.2).

GAS TEMPERATURE

The exhaust gas temperatures are fairly constant, and boilers and furnaces operate with stack gas temperatures of 285 to 590°F with a mean of 450°F (Table II-1.2). There is some indication that larger boiler units have hotter exhaust temperatures than small units.

GAS VELOCITY

No information was available to determine stack gas velocities. Because of the adverse effects of high velocities a maximum velocity of 20 to 30 feet per second (fps) is probably common to these furnace stacks. Domestic and industrial/commercial buildings using anthracite will use natural draft so the most economical stack diameter can be calculated from Appendix A.

STACK HEIGHT

Domestic and industrial/commercial buildings using anthracite will range in height from 20 to 100 feet. Where specific stack height is not available, use 60 feet.

TABLE II-1.1 Analyses of Anthracite Coal from Pennsylvania[5]

County, town, and mine	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Btu	Btu, dry basis
Dauphin County							
Lykens:							
Underkoffler	2.0	8.2	78.9	12.9	.6	12,990	13,260
	2.5	7.4	78.9	13.7	.6	12,770	13,100
Lackawanna County							
Carbondale:							
Raymond	7.4	7.1	81.1	11.8	.8	12,180	13,150
	9.3	7.3	80.7	12.0	.7	11,860	13,080
Luzerne County							
Ashley:							
Huber	3.7	5.3	85.5	9.2	.8	13,140	13,650
	3.1	5.5	83.5	11.0	.9	12,900	13,310
	4.1	5.2	83.4	11.4	.7	12,680	13,220
	4.7	5.5	84.0	10.5	.8	12,750	13,380
	7.1	5.6	85.0	9.4	.7	12,640	13,610
	7.2	5.6	83.1	11.3	.8	12,300	13,250
	7.7	5.7	83.7	10.6	.8	12,350	13,380
Fern Glen: Gowen	6.6	5.6	83.8	10.6	.5	12,260	13,130
Hazelton: Hazelton Shaft	7.4	4.7	85.3	10.0	.6	12,220	13,200
McAdoo (Schuylkill County):							
Beaver Brook (Redco)	8.3	5.4	85.2	9.4	.6	12,240	13,350

TABLE II-1.2[3,4]

Exhaust Gases From Anthracite Coal Combustion

Actual Boiler Output 10^6 BTU/hr.	Coal Input Rate lb./hr	Exhaust Flow scfm	Exhaust Temp.* ^oF	Excess air %	Operating Load %	Heat efficiency %
1.30	140	490	390	83	53	77
1.87	200	550	445	52	75	82
1.88	208	595	445	50	76	76
1.90	206.9	590	445	69	79	79
1.96	191.8	585	475	50	79	82
1.97	193.4	520	480	37	77	83
2.21	220.9	530	495	28	89	82
2.38	266.8	600	540	18	96	74
2.46	254.8	650	535	28	99	77
2.65	286.6	630	540	31	107	74
0.48	62.9	330	285	200	19.7	64
0.63	76.6	430	315	200	25.6	69
1.06	110.5	420	355	92	43	79
1.06	106.7	385	380	85	43	84
1.41	150.9	610	400	97	57	79

*Exhaust temperature measured at boiler flow outlet.

TABLE II-1.2 [3,4,31,33,34]

Exhaust Gases From Anthracite Coal Combustion (continued)

Actual Boiler Output 10^6 BTU/hr.	Coal Input Rate lb./hr	Exhaust Flow scfm	Exhaust Temp.* ^oF	Excess air %	Operating Load %	Heat efficiency %
1.38	172.1	590	445	94	56	65
1.44	179.0	700	440	95	58	65
1.49	157.4	510	460	62	60	78
1.77	210.7	840	485	72	72	70
1.78	197.0	780	490	80	72	74
1.89	221.8	770	480	94	76	73
2.42	301.6	960	550	71	98	66
2.45	296.6	830	550	63	99	67
2.47	285.9	970	560	82	100	71
2.59	311.3	830	560	63	105	68
2.60	304	870	540	57	105	72
2.65	328	880	555	66	107	66
3.10	407	1200	560	55	125	62
3.14	380	870	585	53	126	67
3.38	486	1050	590	70	136	56

*Exhaust temperature measured at boiler flow outlet.

TABLE II-1.2[3,4]

Exhaust Gases From Anthracite Coal Combustion (continued)

Actual Boiler Output 10^6 BTU/hr.	Coal Input Rate lb./hr	Exhaust Flow scfm	Exhaust Temp.* ^oF	Excess air %	Operating Load %	Heat efficiency %
1.64	176.8	590	420	75	65	77
1.96	209.9	650	475	57	79	77

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*Exhaust temperature measured at boiler flow outlet.

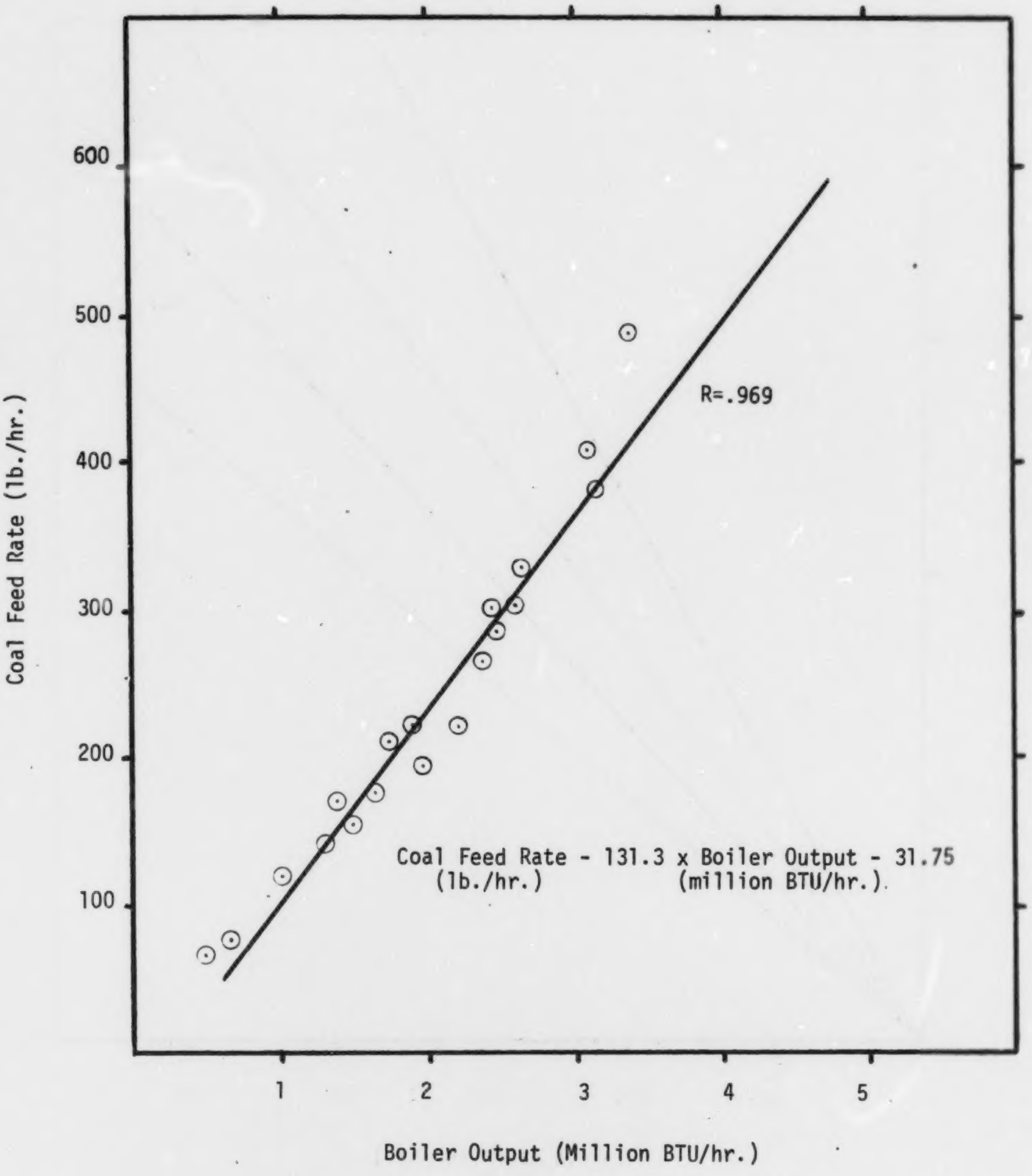

Figure II-1.1 Anthracite coal requirements for various heat production rates

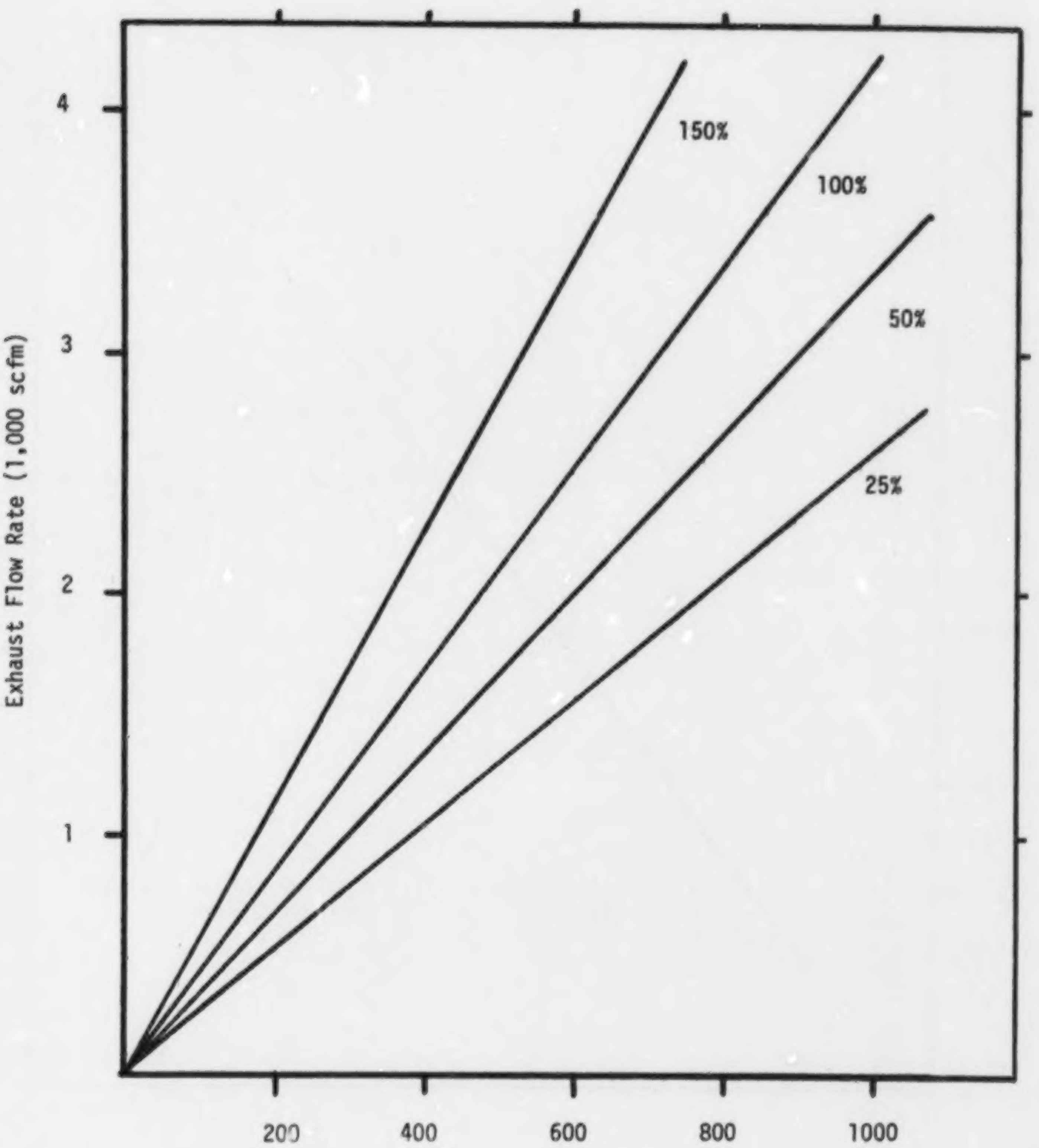

Figure II-1.2 Calculated exhaust flow rates at several excess air percentages for anthracite coal production.

CHAPTER II-2

BITUMINOUS COAL COMBUSTION[A]

"Power Plants"

Bituminous coal is commonly used as a boiler fuel throughout the United States because of its wide availability and low price. Over 50 percent of the U.S. bituminous coal production is consumed by one category, the electric power utilities.[6] Except in the southwest (Texas, Oklahoma, Louisiana) where natural gas is abundant, coal supplies the majority of the energy for the generation of electricity. Residual oil has made recent inroads because of sulfur-in-fuel regulations, but bituminous coal still accounts for 61 percent of the total heat energy used by power plants.

While most bituminous coal is produced in the Appalachian Mountain region, coal and lignite fields elsewhere supply fuel for local consumption. Information on heat value of coals from various fields shows a wide range (10,000 - 14,000), but most coals average about 12,000 BTU/lb. (Table II-2.1)[7]. Specific heat values and other analyses may be obtained in the U. S. Bureau of Mines annual publication, "Analysis of Tipple and Delivered Samples of Coal" (Table II-2.2)[5].

Generating stations commonly pulverize coal before firing to increase boiler efficiency and ensure complete combustion. The best large steam - electric power plants reportedly have heat requirements of about 8500 BTU/kw-hr with a plant thermal efficiency of 0.40 (Table II-2.3)[8]. The data from Federal Power Commission records (Table II-2.4) confirm this value; the data were taken from the largest power stations in the U.S.[9]

Power output for large coal fired boiler units is generally given in megawatts and is usually displayed by power plants on information plaques at the plants. Such information also is published by the Federal Power Commission[9] and National Coal Association[7].

In 1970 the Federal Power Commission began collecting air and water pollution emission data from all public utility power generating stations in the U. S. The information is made available for public inspection through the Office of Public Inspector, Federal Power Commission, Washington D. C. Available data includes air and water emissions, fuel quality and quantity, effluent flow rates, power generated, and several other items of economic and engineering benefit regarding air and water pollution control.[9] Data from over 50 power plants located in 15 states were randomly selected to provide input-output, gas flow rate, temperature, velocity, and stack height information (Table II-2.4).[9,11,14,15]

The major pollutants emitted from combustion of bituminous coal are particulates, sulfur oxides and nitrogen oxides. Abatement equipment presently is used only for particulates. In the present state-of-the-art, no means have shown success in the control of oxides of nitrogen or sulfur. The most common device used to control particulate emissions is the electrostatic precipitator. (Precipatators are often preceded in the flue gas effluent stream by a cyclone or other similar type of mechanical collector to remove large particles.) There is no significant temperature drop (less than a 5% drop) across the precipitator, since most are well built and insulated.[12,13]

Coal input rate for generating a unit of electricity is most directly a function of the coal heat value (Equation II-2.1); however, boiler efficiency and chemical analyses of the coal also affect coal usage. On the average, 8.8 million BTU of energy are required to generate 1 megawatt-hour of power. Data from several different generating stations illustrate the relationship provided by Equation II-2.1 (Figure II-2.1).

(Equation II-2.1 was based on 12,000 BTU/lb. heat value and an average boiler efficiency of 85%.)

$$\underset{\text{(tons/hr.)}}{\text{Coal Firing Rate}} = \frac{\text{Power Production (mw.)}}{\text{Coal Heat Value (BTU/lb)}} \times \frac{8.8\ \text{(BTU)}\ 1\ \text{(ton)}}{\text{(mw.-hr.)}\ 2000\ \text{(lb.)}} \qquad \text{II-2.1}$$

The operating loads of electrical generating units vary according to time of day, day of the week and season of the year. Highest combustion efficiency is attained when operating at 100% of design capacity, so most pulverized boiler units, when running, tend to operate at that loading. It is more practical to run fewer units at full load than to run all units at partial loads. Peak demands occur for summer air conditioning and winter heating loads.

GAS FLOW RATE

Exhaust flow rate is governed by the quantity of coal burned, excess air rate and chemical analysis of the coal. Excess air is added to enhance complete oxidation/combustion of all carbon in the coal. It is common practice for pulverized coal boiler units above 100 MW capacity to use between 12 and 25% excess air, while smaller boiler units require 40 to 50% excess air. The trend today is toward lower excess air which results in higher combustion efficiency and less NO_x. One large power plant uses only 10% excess air for its pulverized coal furnaces. Most power plants have charts and records available on air flow rates, fuel usage, and combustion efficiency. Where specific data is not available Figure II-2.2 can be used to estimate exhaust flow rates at standard conditions (70° F and 760 mm Hg). Exhaust gas flow ranges from 1,750 - 2,000 scfm/megawatt. For calculations, assume 2,000 scfm/megawatt.

GAS TEMPERATURE

Flue gas temperatures depend on efficiency of combustion, whether air preheaters are used, excess air rates, firing rate and type of firing unit. However, one important consideration in determing the minimum exit temperature is the sulfuric acid dew point which is about 250°F. Sulfuric acid corrodes combustion chamber walls and results in costly repairs. By making sure that the stack gases are always above the sulfuric acid dew point, formation of sulfuric acid mist can be minimized. Flue gas exit temperatures for 55 randomly selected pulverized units ranged from 235 to 370°F with a mean of 280°F (Figure II-2.3). For calculations, assume 280°F.

GAS VELOCITY

The only emission point for power plants is a tall stack. Stack diameters are used to control velocity and these diameters usually range from 12 to 25 feet depending on exhaust gas throughput. Stacks are usually made of concrete. It is desirable to have exit velocities below 60 fps to prevent aerodynamic vibrations within the stack. Otherwise, added strain may lead to rapid deterioration of the stacks. Appendix A is offered to facilitate calculation of ideal velocities.

From Federal Power Commission data, exit velocities were calculated from maximum exhaust flow and stack diameters (Figure II-2.4). Most velocities ranged from about 40 to 60 fps with an average of about 50 fps. Where specific data are not available 50 fps should be used in calculations.

STACK HEIGHT

The trend today is toward taller stacks to enhance gas dispersion and lower ground level concentrations of pollutants. However, in rough complex terrain tall stacks (even those 500 feet above the surface) are not always effective.[11] Data from the Federal Power Commission records were plotted as a histogram to show the range of stack heights (Figure II-2.5). The range was 124 to 600 ft. with a typical height of 300. Where specific data are not available 300 feet should be used for calculations.

CHAPTER II-2

BITUMINOUS COAL COMBUSTION

"Industrial/Commercial Plants"

Stoker fired boiler units are used mainly for generating industrial process steam, commercial space heating and commercial refrigeration (air conditioning). They are commonly found in many central heating plants for government buildings, institutions, hospitals, universities, apartment complexes and factory power houses. Their use is declining as gas and oil-fired units require less space and less labor. Pulverized coal-fired boilers would be considerably more efficient, but they can not be used economically for small and medium scale steam production below 300,000 lb./hr. Small boilers often have wide variations in operating loads, and stoker fired furnaces are uniquely suited to this fluctuating demand.[16] Stoker units, both underfeed and spreader, use a "nut" coal.

Efficiencies of these furnaces and boilers vary considerably, but data available from several Federal government installations showed a typical boiler efficiency of 75 percent.[16] In other words, 250,000 lb./hr. of steam (250 million BTU/hr. output) will require 330 million BTU/hr. of heat input (Table II-2.5).

Cyclones or other dry collectors are commonly used to reduce solid particulate emissions.[17,18] Because the fly ash has some heat value, fly ash reinjection may increase boiler thermal efficiency yet, at the same time, increase particulate emissions to the atmosphere.

GAS FLOW RATE

Exhaust gas flow rates are dependent on excess air rates which commonly range from 50 to 200 percent in stoker fired boilers to prevent smoking. For new Federal boilers, the National Academy of Sciences (NAS) recommends that specifications require the boiler to be able to operate at 25 percent excess air down to 33 percent of maximum load.[19] The NAS also specifies capabilities of the combustion controls on changing loads. It is safe to assume that operating practices will generally show less efficient operations than required by specifications. Also, in practice, where steam demand is fluctuating, the combustion air flow rate is held fairly constant and the coal feed rate is increased or decreased to meet the load demand. By such operation, excess air may go from 50 percent at maximum load to 200 percent at 20 percent of maximum steam load. Where specific information is not available, it is recommended that 50 percent be used (Figure II-2.6 and II-2.7) in calculations. From the curves one can observe that an average exhaust flow rate of 200 scfm can be expected for each 1 million BTU/hr. heat input.

GAS TEMPERATURE

Most stoker fired boilers or furnaces in industrial or commercial applications will be outfitted with a mechanical collector to reduce particulate emissions but little change in temperature will be noted. Data obtained for 25 plants showed actual stack gas temperatures to range from 292 to 906 °F with an average value of 527°F. For calculations use 500°F for exhaust gas temperatures.

GAS VELOCITY

No empirical data on stack gas exit velocity was found for stoker fired units. It is recommended that Appendix A be used to estimate stack diameters and exit velocities. Otherwise assume about 30 fps.

STACK HEIGHT

The stacks for stoker fired units are usually made of metal and are about 2-3 feet in diameter. Often they extend through the tops of buildings and protrude about 10 feet. Since industrial/commercial buildings range from 20 to 100 feet in height, assume 60 feet for calculations.

TABLE II-2.1

TYPICAL HEAT VALUES OF FUELS USED BY POWER PLANTS (1968)

Region and State	Number of Power Plants	Average B.T.U. Content as Burned		
		Coal (lb.)	Oil (gal.)	Gas (Cu.ft.)
NEW ENGLAND				
Connecticut	13	12,679	149,054	1,033
Maine	5	-	149,611	-
Massachusetts	28	12,637	148,911	999
New Hampshire	5	13,769	149,767	-
Rhode Island	4	13,614	149,888	1,040
Vermont	1	13,744	-	-
MIDDLE ATLANTIC				
New Jersey	18	13,127	148,255	1,037
New York State	34	13,124	148,320	1,036
New York City	17	13,517	148,321	1,035
New York State (Excl. NYC)	17	12,909	146,128	1,038
Pennsylvania	41	12,220	149,006	989
Philadelphia	9	13,434	149,314	979
Pennsylvania (Excl. Phil)	32	11,974	138,300	1,040
EAST NORTH CENTRAL				
Illinois	42	10,684	148,895	1,043
Indiana	33	11,154	138,050	1,013
Michigan	37	12,463	138,810	1,042
Ohio	50	11,661	140,195	1,039
Wisconsin	26	11,888	134,647	1,020
WEST NORTH CENTRAL				
Iowa	40	10,734	141,880	1,020
Kansas	34	12,037	150,110	1,003
Minnesota	40	11,162	145,083	1,012
Missouri	35	10,845	145,250	971
Nebraska	18	12,216	150,914	1,006
North Dakota	15	6,909	144,369	1,054
South Dakota	10	8,371	149,425	1,007
SOUTH ATLANTIC				
Delaware	5	13,055	150,125	1,037
District of Columbia	2	13,139	147,516	-
Florida	37	11,513	149,574	1,014
Georgia	11	12,285	147,227	1,040
Maryland	11	12,976	148,559	1,025
North Carolina	16	12,627	140,873	1,049
South Carolina	12	12,659	148,013	1,044
Virginia	12	12,964	140,939	1,040
West Virginia	11	11,889	137,402	1,100

TABLE II-2.1

TYPICAL HEAT VALUES OF FUELS USED BY POWER PLANTS (1968)(Continued)

Region and State	Number of Power Plants	Average B.T.U. Content as Burned		
		Coal (lb.)	Oil (gal.)	Gas (Cu.ft.)
EAST SOUTH CENTRAL				
Alabama	11	11,869	-	1,046
Kentucky	16	11,281	138,393	1,035
Mississippi	12	12,582	146,754	1,048
Tennessee	7	11,682	-	1,048
WEST SOUTH CENTRAL				
Arkansas	8	-	148,793	1,019
Louisiana	21	-	148,589	1,070
Oklahoma	18	12,975	148,105	1,039
Texas	77	-	143,619	1,040
MOUNTAIN				
Arizona	11	10,528	149,677	1,072
Colorado	22	10,667	151,121	893
Montana	5	7,030	153,042	1,178
Nevada	5	12,665	146,818	1,069
New Mexico	16	8,944	150,009	1,062
Utah	10	12,663	155,105	931
Wyoming	8	7,965	136,905	1,050
PACIFIC				
California	39	-	149,899	1,075
Oregon	2	-	153,571	1,053
Washington	6	-	156,553	-
UNITED STATES TOTAL	940	11,769	148,971	1,043

TABLE II-2.2 Chemical Analyses of Bituminous Coal[5]

(Pennsylvania, Fayette Co., Pittsburg Bed Illustrated)

Proximate, percent				Ultimate, percent					Calorific Value
	Dry Coal								
Moisture, as-received coal	Volatile Matter	Fixed Carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, dry basis
3.6	30.8	60.5	8.7	1.3	5.0	78.3	1.8	4.9	13,970

TABLE II-2.3

Thermal Efficiencies for Different Size Boiler Units[8]

Type of Heat	Plant heat rate B.t.u./kw.-hr.	Plant thermal efficiency
All stationary steam plants, average	25,000	0.14
Central-station steam plants, average	11,500	0.30
Best large central-station steam plant	8,500	0.40
Small non-condensing industrial steam plant	35,000	0.10
Small condensing industrial steam plant	20,000	0.17
"By-product" steam power plant	4,500-5,000	0.70-0.75
Diesel plant	11,500	0.30
Natural-gas-engine plant	14,000	0.24
Gasoline-engine plant	16,000	0.21
Producer-gas-engine plant	18,000	0.19

TABLE II-2.4[9,11,14,15]

Exhaust Gases From Bituminous Coal Fired Power Plants

Electric Generating Capacity mw.	Steam 1000 lb./hr.	Input Rate at 100% load tons/hr.	Exhaust Flow at 100% load 1000 scfm	Exhaust Temp. °F	Exit Velocity at Stack Condtns fps	Stack Height ft.	Stack Diameters ft.	Boiler Efficiency %	Excess Air %
191	1357	65	511	245				92	15
191	1357	65	511	245				92	15
99	750	44.6	285	370	80	292	11	86	18
99	750	44.6	285	370	80	292	11	86	18
99	750	44.5	305	360	74	292	11	87	22
99	750	44.5	305	360	74	292	11	87	22
256	1500	92	700	255				90	24
	950	46	339	266	59	295	13	88	22
233	1715	85	640	240				91	22
123	875	53	380	262	42	300	16	87	22
123	875	53	380	262	42	300	16	87	22
123	875	53	380	262	42	300	16	87	22
208	1500	92	580	235	51	300	18	89	22
225	1613	119		264		250	18.5	87	13

TABLE II-2.4

Exhaust Gases From Bituminous Coal Fired Power Plants (Continued)

Electric Generating Capacity mw.	Steam 1000 lb./hr.	Input Rate at 100% load tons/hr.	Exhaust Flow at 100% load 1000 scfm	Exhaust Temp. °F	Exit Velocity at Stack Condtns fps	Stack Height ft.	Stack Diameters ft.	Boiler Efficiency %	Excess Air %
115	865	54	47.3	264		250		88	15
540		183		280	56	550	22	90	20
540		183		280	56	550	22	90	20
180		75	600	280	71	300	16	90	20
225		80		290		500	25	90	20
	1700	95	639	275	80	200	15.5	89	15
	2568	138.5	826	269	75	600	18	89	18
	1750	95	555	262	31	600	25	89	18
	1800	97	607	260	69	296	16	90	20

TABLE II-2.4

Exhaust Gases From Bituminous Coal Fired Power Plants (Continued)

Electric Generating Capacity mw.	Steam 1000 lb./hr.	Input Rate at 100% load tons/hr.	Exhaust Flow at 100% load 1000 scfm	Exhaust Temp. °F before	after	Exit Velocity at Stack Condtns fps	Stack Height ft.	Stack Diameters ft.	Boiler Efficiency %	Excess Air %
	1100	64.5	398.8	290	280					40
	1100	65.2	411.3	280	276					40
	1100	67.0	419.5	265	255					45
	830	48.0	300.4	230	220					41
	800	46.2	307.3	260	250					38
	920	55	321	260	255					36
	640	39	259	243	248					30
	860	52	326	260	260					35
	860	49.5	337	250	250					
	635	38.5	252	245	240					36
	960	55.0	336	280	279					28
	693	42.7	256	243	241					23
	960	59	362	286	261					30
	960	54.2	355	283	284					27

TABLE II-2.4

Exhaust Gases From Bituminous Coal Fired Power Plants (Continued)

Electric Generating Capacity mw.	Steam 1000 lb./hr.	Input Rate at 100% load tons/hr.	Exhaust Flow at 100% load 1000 scfm	Exhaust Temp. °F		Exit Velocity at Stack Condtns fps	Stack Height ft.	Stack Diameters ft.	Boiler Efficiency %	Excess Air %
				before	after					
	700	39	272	263	264					27
	149	8.8	60.3	310	305					45
	152	10.8	65.6	312	305					38
	149	9.1	65.0	311	305					48
	105	6.4	44.9	318	316					42
	111	6.7	44.3	310	301					37
	147	9.5	57.7	326	315					24

TABLE II-2.5

Exhaust Gases From Bituminous Coal Stoker-Fired Heating Plants [20,21]

Steam Rate 1000 lb./hr.	Input Rate 1000 lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Excess Air %	Efficiency (%)
3.5	0.38	1.37	775	56	61
5.1	0.64	2.54	906	81	55
3.9	0.42	1.54	573	66	69
5.6	0.55	2.22	725	62	68
6.3	0.62	2.31	700	62	68
10.9	1.10	3.33	684	36	68
5.6	0.53	2.38	537	100	70
40.7	4.28	14.00	659	49	69
52.8	6.25	24.00	533	84	64
23.4	1.91	5.89	510	37	82
21.3	2.21	6.97	662	44	70
121.0	1.40				
80.0	80				
			292		87
			297		85

TABLE II-2.5

Exhaust Gases From Bituminous Coal Stoker-Fired Heating Plants [20,21] (cont'd)

Steam Rate 1000 lb./hr.	Input Rate 1000 lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Excess Air %	Efficiency (%)
			387		85
			386		84
			326		84
			502		78
			455		73
			513		79
			521		80
			566		75
			581		79
			520		79
			569		78

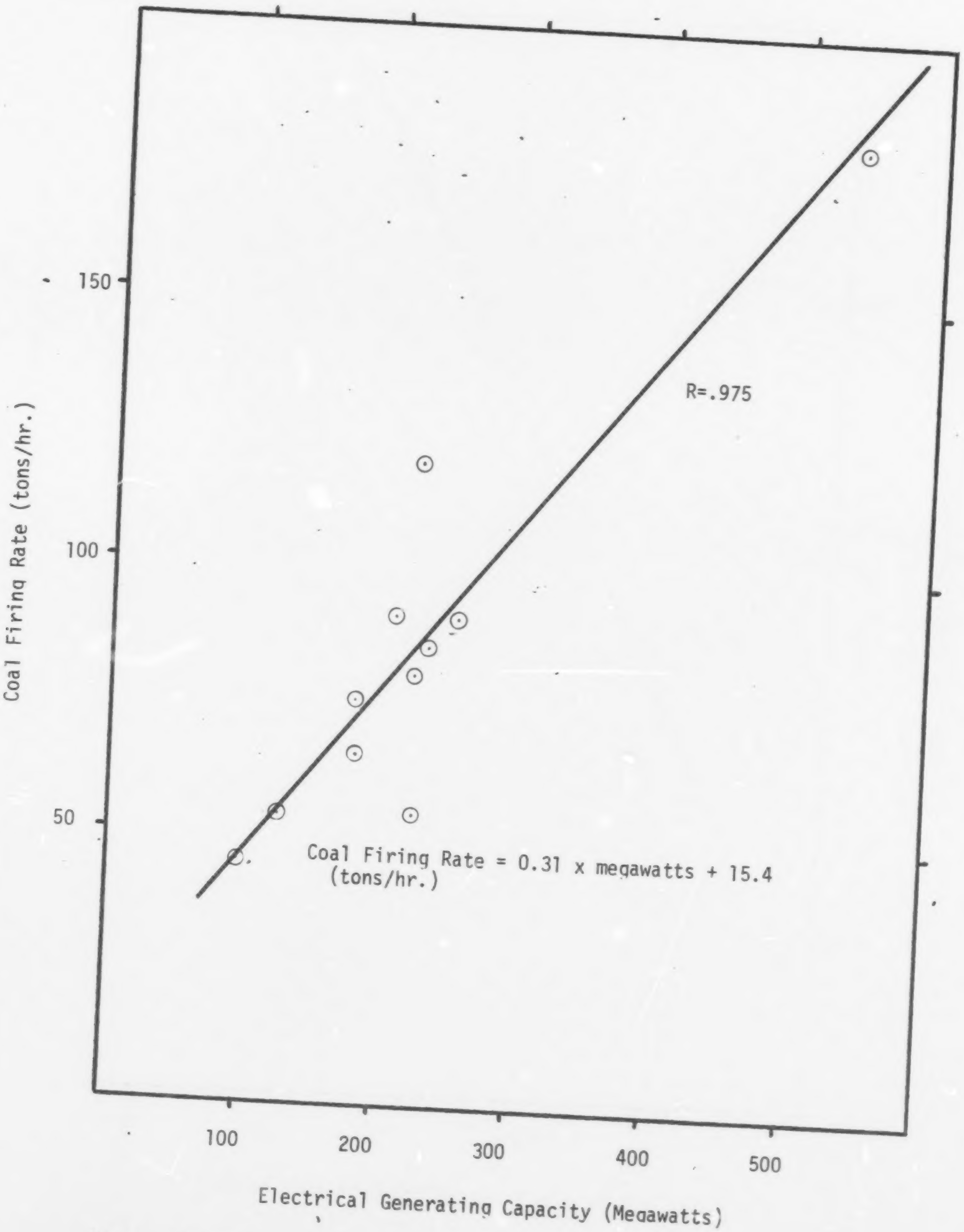

Figure II-2.1 Pulverized coal firing rate vs. electrical generating capacity.

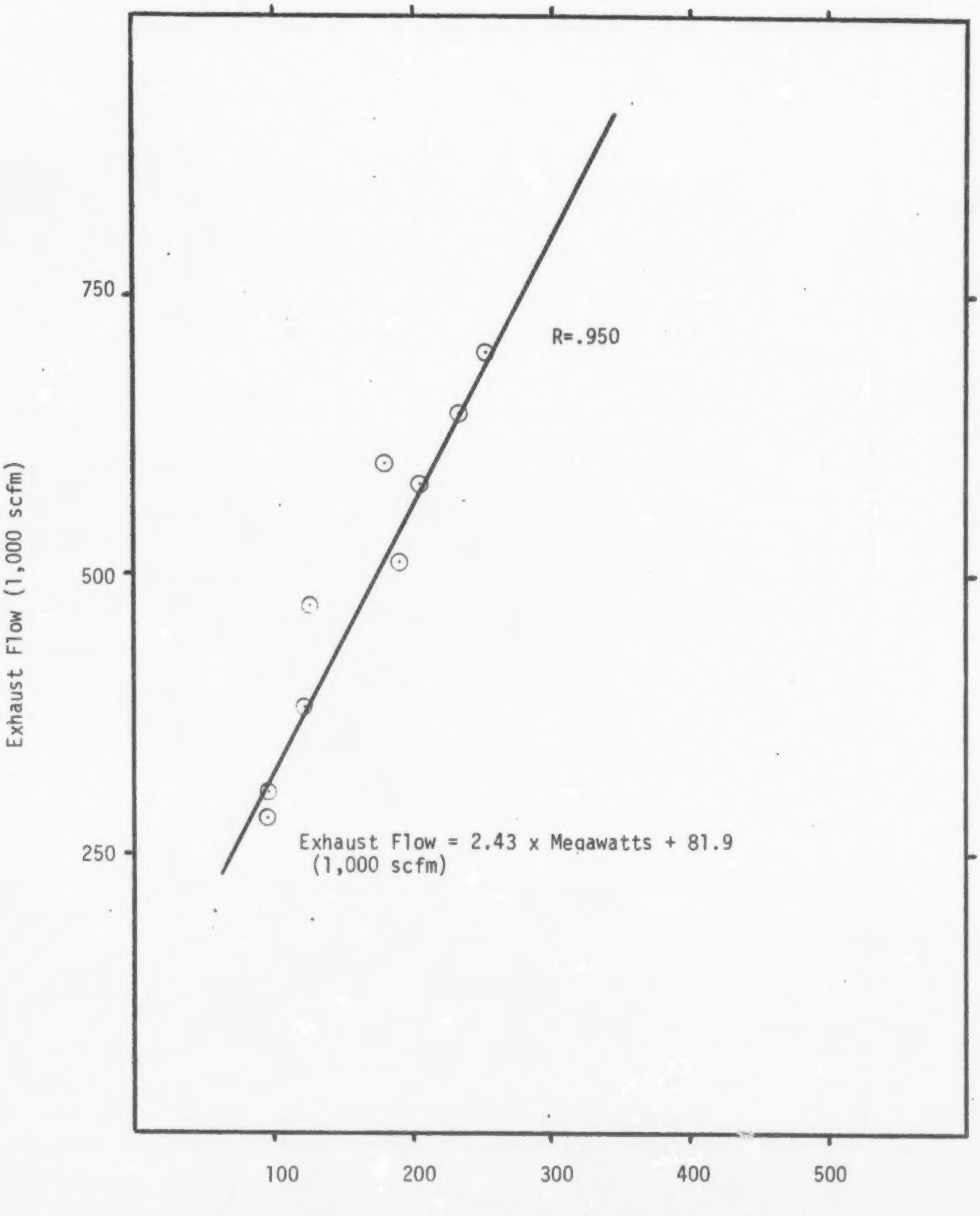

Figure II-2.2 Exhaust gas flow rate vs. electrical generating capacity for coal fired power plants

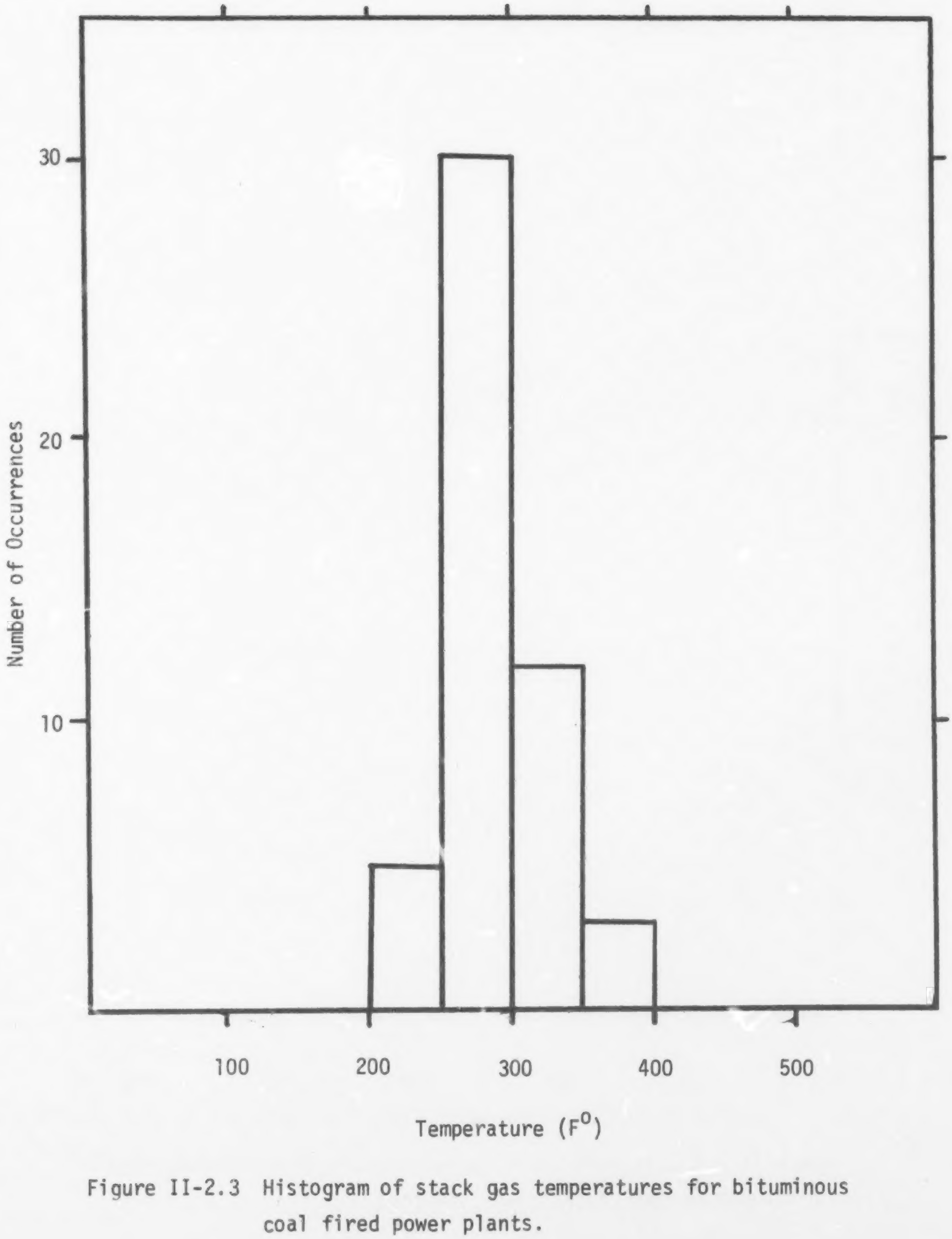

Figure II-2.3 Histogram of stack gas temperatures for bituminous coal fired power plants.

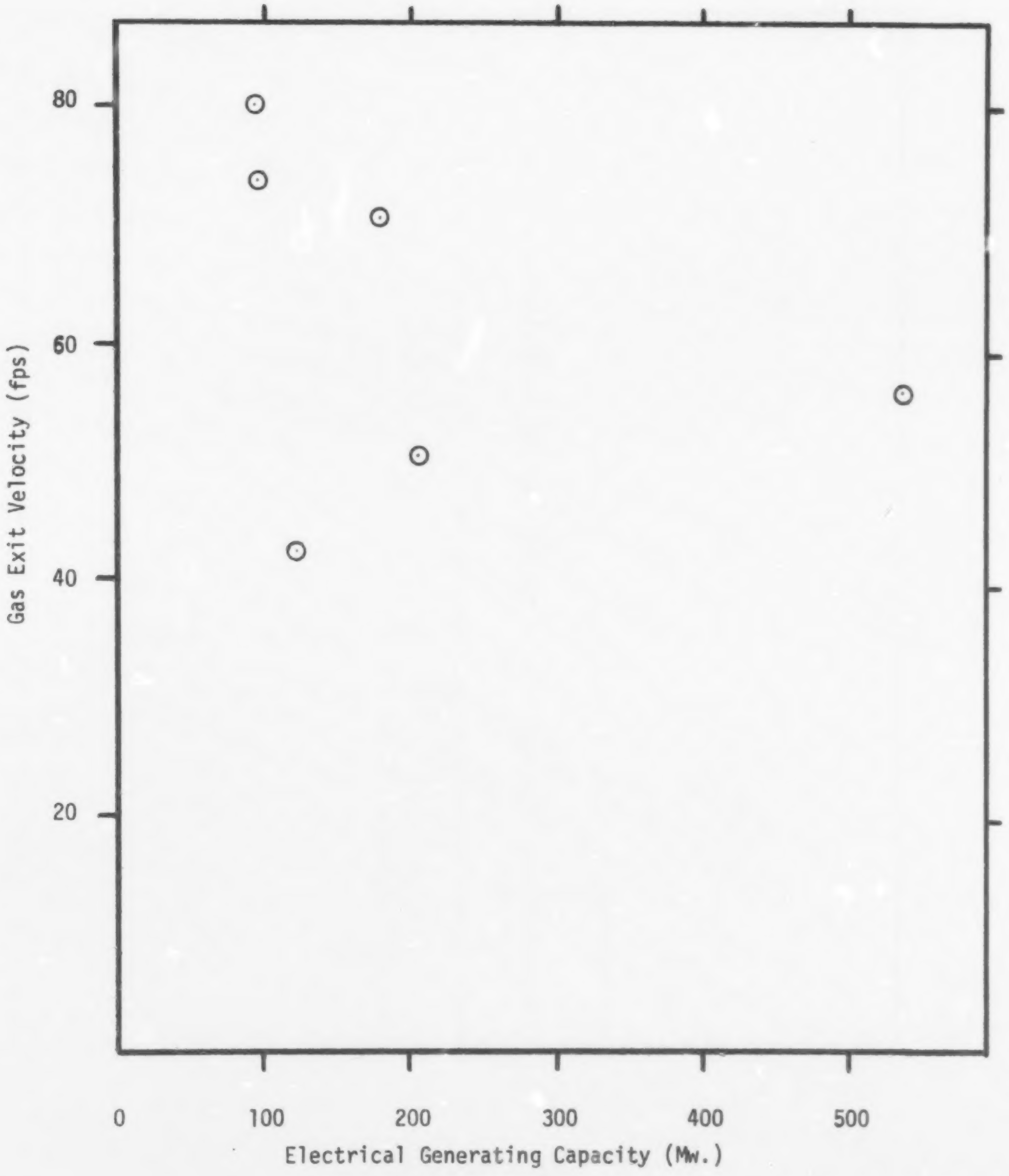

Figure II-2.4 Gas exit velocity vs. electrical generating capacity for bituminous coal fired power stations.

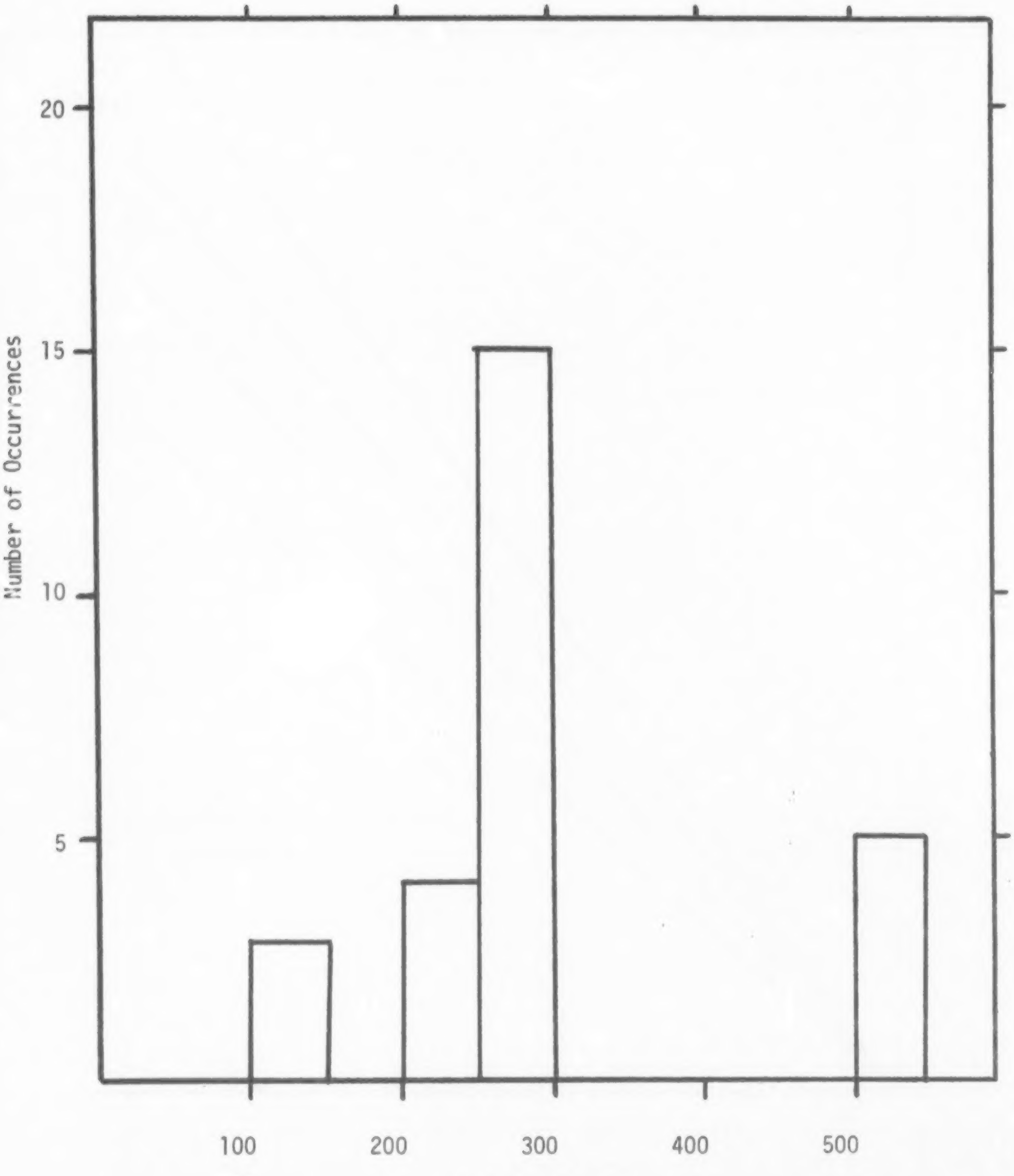

Figure II-2.5 Histogram of stack heights for power plants.

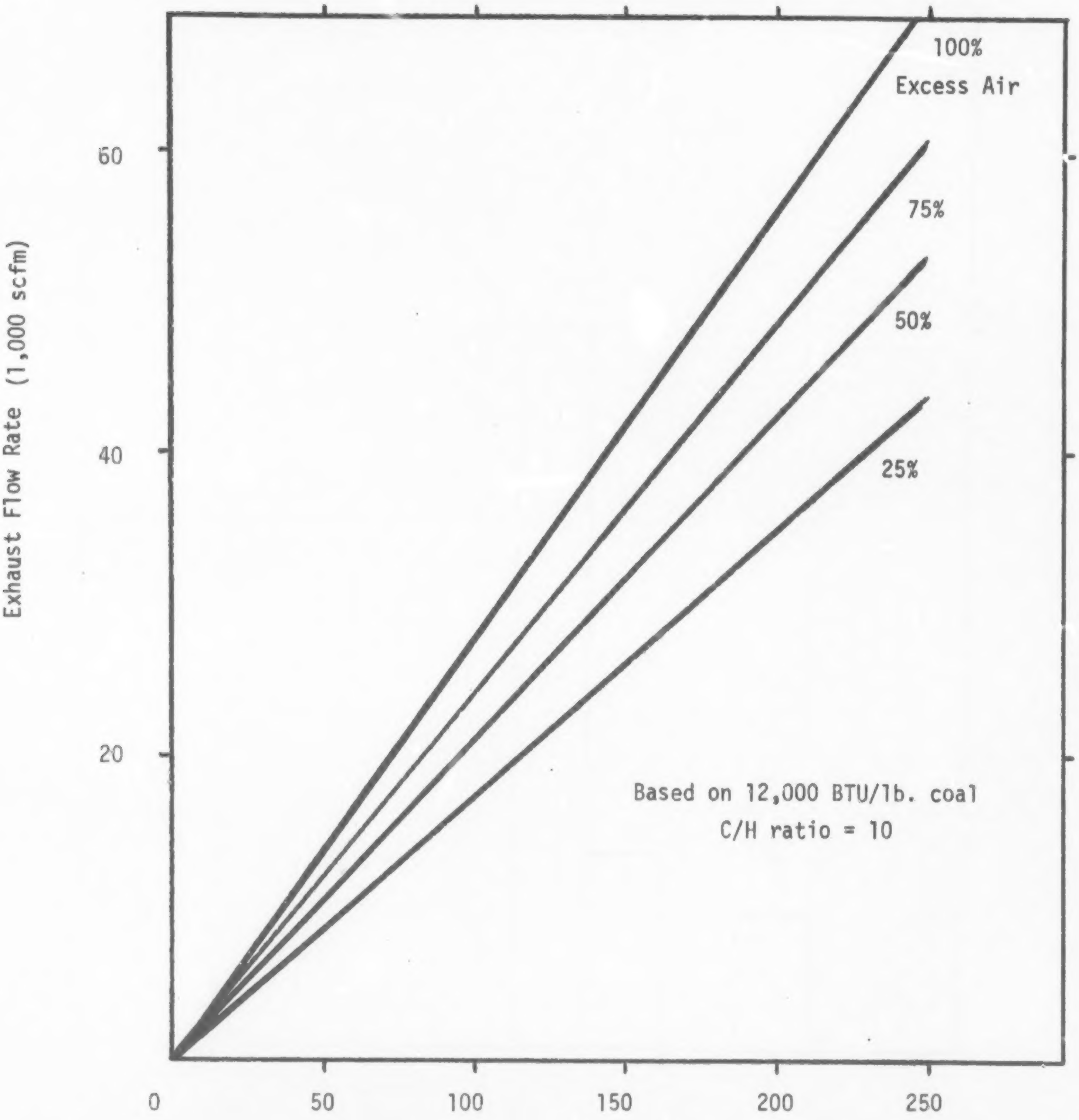

Figure II-2.6 Calculated exhaust flow rate for stoker fired combustion units

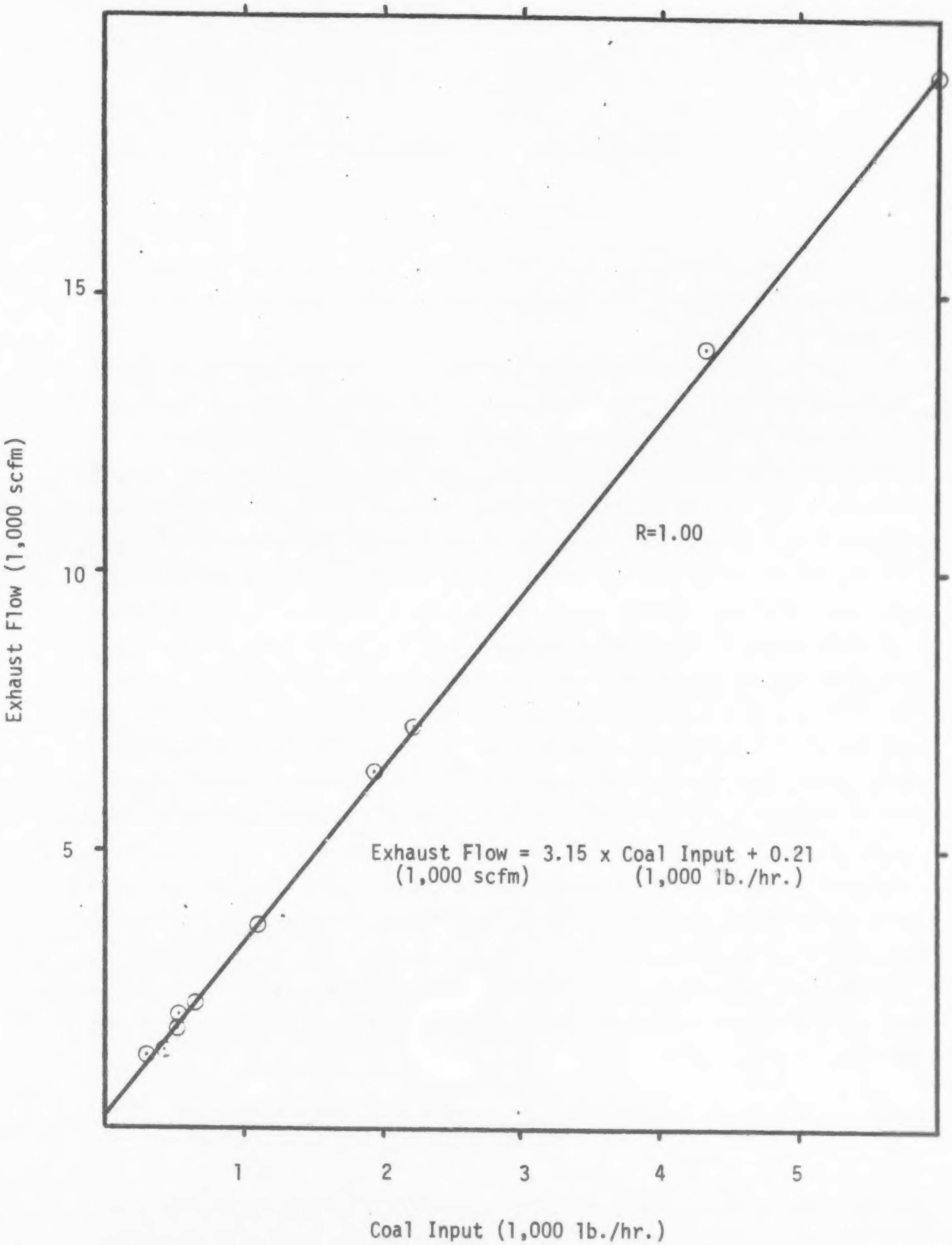

Figure II-2.7 Bituminous coal feed rate vs. exhaust flow for stoker fired combustion units (50% excess air)

CHAPTER II-3

RESIDUAL FUEL OIL COMBUSTION [A]

"Power Plants"

As its name indicates, "residual oil" is the heavy residue that is left during the refining process when lighter oils, such as kerosene and gasoline, are removed.

Typical analyses of fuel oils for the U.S. are available from an annual government publication, "Burner Fuel Oils," U. S. Department of Interior.[22]

For some time, investigators thought that oil additives played a significant role in increasing fuel oil combustion efficiency and reducing total fuel oil air pollution. A status report of tests on oil additives conducted by EPA indicates that only minimal gains are attained in combustion efficiency and reduction of air pollution.[23] Unless otherwise indicated, the data offered here were assumed to contain no oil additives.

Most residual oil fired power plants will have no sophisticated air pollution control equipment; however, some plants use mechanical collectors (cyclones and multiple cyclones) during soot-blowing operations. The overall efficiency of the mechanical collectors is about 60 percent, collecting mainly particles larger than 10 microns.[24] The current trend in new air pollution regulations to reduce visible emissions may require use of electrostatic precipitators in the future. Presently, there are 2 or 3 generating plants which are installing electrostatic precipitators. As mentioned earlier, there is no significant change in the gas conditions when precipitators or mechanical collectors are used.

The fuel oil consumption rate is directly related to power production rate as described earlier for pulverized coal. Equation II-3.1 gives the approximate relationship.

$$\text{Fuel Oil Input (gal./hr.)} = \frac{\text{Power Production Rate (mw.)}}{\text{Heat Value (BTU/lb.)}} \times \frac{\text{8.8 (BTU}}{\text{(mw.-hr.) 8.212(lb./gal.)}} \qquad \text{II-3.1}$$

Another common way of designating boiler capacity is the steam generated (lb. steam per hour). Since 1 lb. of oil burned per hour will generate 13.8 lb. of steam per hour, based on the plot of the empirical data in

Figure II-3.1, Eq. II-3.2 provides another important relationship when the boiler capacity is known.

$$\text{Fuel Oil Input (gal./hr.)} = \frac{\text{Boiler Capacity (lb.steam/hr.)}}{\text{110 (lb. steam/gal.)}} \qquad \text{II-3.2}$$

Specific power plant data can be obtained from the Federal Power Commission.[9] A plot of the data from randomly selected power plants (Table II-3.1) shows fuel input as a function of output in steam capacity and power production rate (Figure II-3.1).[9,14]

GAS FLOW RATE

Exhaust flow rates for large fuel oil combustion units follow a linear relationship as can be seen from Figure II-3.2. Larger units may be operated more carefully than smaller units because of the efficiency.

Power plants tend to use about 20% excess air while industrial furnaces average near 90%.[25] The theoretical air flow closely approximates the actual flow rate with an accuracy of ± 15%. As can be seen from Figure II-3.2, approximately 27,200 standard cubic feet of exhaust gases can be expected for every 1000 gallons of residual oil fired.

GAS TEMPERATURE

The same temperature considerations which are necessary in coal furnaces are also valid for oil fired units. The sulfuric acid dew point temperature is an important operating temperature factor. As in the case of coal furnaces, the exhaust temperature is related to the amount of excess air used in the system. Since the boiler efficiencies of larger units approaches stoichiometric conditions, there is little variation in air fuel requirements and, thus, little variation in exhaust gas temperatures. Table II-3.1 shows exit gas temperature ranges for residual fuel oil combustion with most data falling in the 250 - 350°F range. Where specific information is not available 300°F should be assumed.

GAS VELOCITY

Using data provided on stack diameters and exhaust gas flow rates from the Federal Power Commission, velocities were calculated. Velocities ranged from 20 to 100 fps; where specific data are unavailable 40 fps should be assumed.

STACK HEIGHT

Stack heights typically ranged from 110 to 450 feet with an average of about 190 feet. When specific information is not available use 200 feet for dispersion calculations.

CHAPTER II-3

RESIDUAL FUEL OIL COMBUSTION

"Industrial/Commercial Plants"

Small boilers consuming less than 2,500 pounds of oil per hour (315 gallons) are principally used for producing industrial process steam and space heat. These units usually are less efficient in combustion than the power plants and are given less attention by the operators. For this reason, one can expect to find wider fluctuations in fuel input, air requirements, excess air and exhaust gas temperatures for these units. The smallest size boiler that will use residual fuel oil is about 2.5 million BTU/hr. capacity; smaller units generally will use No. 2 oil.

The fuel oil input and steam capacity are shown in Figure II-3.3. The figure shows that 1 pound of oil will generate 12 pounds of steam, compared to 13.8 for power plants.

GAS FLOW RATE

Some of the data plotted in Figure II-3.4 were from boilers which used extreme amounts of excess air (43 to 180%) in the combustion processes. Although these are actual data being reported, they tend to show poor combustion efficiencies because of the high quantities of air used. Optimum efficiency for small units can be attained with 20 - 30% excess air. Based on available data, the average excess air rate for units burning less than 2,500 lb./hr. was 60%. The figure shows that about 50 standard cubic feet of exhaust gases can be expected for each gallon of residual fuel oil burned. An earlier reference used 213 cubic feet per pound (1700 cubic feet per gallon) which agrees with the data in Figure II-3.4; in general, the theoretical exhaust rates are less than actually measured in the field.

GAS TEMPERATURE

Excess air affects exhaust gas temperatures. Some of the data which appear in Table II-3.2 are from boilers with excess air ranging from 70 to 180 percent. Temperatures ranged from 220 to 710°F. Where specific data are unavailable assume 500°F.

GAS VELOCITY

Maximum exhaust gas velocity would be on the order of 25 to 30 feet per second based on design considerations. Although no data were available for analysis, use 30 fps for calculations.

STACK HEIGHT

Most industrial/commercial buildings have stacks slightly higher than the roof. Typical stack heights, therefore, would range from 20 to 100 feet with 60 feet being typical.

TABLE II-3.1

Exhaust Gases from Residual Fuel Oil Combustion in Large Facilities [26,27,28]

Electric Generating Capacity Mw.	Production Rate 1000 lb. steam/hr.	Input Rate 1000 gal./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Excess Air %	Firing Mechanism
175	1150	10.80	283	300	28	HMA
173	1150	10.90	303	300	28	HMA
80	275	2.34	69	310	44	HMA
41	400	2.74	91	320	35	HMA
220	1410	12.90	334	280	22	HMA
20	215	1.58	47	300	35	HMA
175	1150	10.40	281	300	28	HMA
	410	3.75	116	330	42	HMA
215	1400	13.30	309	280	14	HMA
215	1400	13.60	314	280	17	HMA
215	1390	13.30	309	280	11	HMA
215	1400	13.20	309	280	11	HMA
215	1400	13.60	320	280	11	HMA
215	1400	13.20	351	280	21	HMA

TABLE II-3.1 (Continued)

Exhaust Gases from Residual Fuel Oil Combustion in Large Facilities

Electric Generating Capacity Mw.	Production Rate 1000 lb. steam/hr.	Input Rate 1000 gal/hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Excess Air %	Efficiency %
81	614	9.6	180	282	20	87
125	935	8.5	267	330	20	87
380	2640	22.2	665	298	13	89
380	2640	22.2	665	298	13	89
69	680	5.5	172	382	14	86
60	600	5.0	152	347	14	85
72	680	5.8	166	347	20	86
81	680	5.8	160	382	14	86

TABLE II-3.2

Exhaust Gases From Residual Fuel Oil Combustion in Small Facilities

Production Rate 1000 lb. steam/hr.	Input Rate gal./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Excess Air %	Firing Mechanism
4.14	35.7	1.70	710	68	S.A.
4.31	24.1	1.70	330	180	P.A.
8.45	104.0	4.07	540	43	MCL 7-23
14.70	171.0	10.00	630	110	S.A.
15.75	83.5	4.56	220	107	P.A.
17.25	250.0	12.40	560	92	S.A.
20.00	59.0	3.03	580	95	S.A.
30.00	174.0	7.40	530	73	S.A.

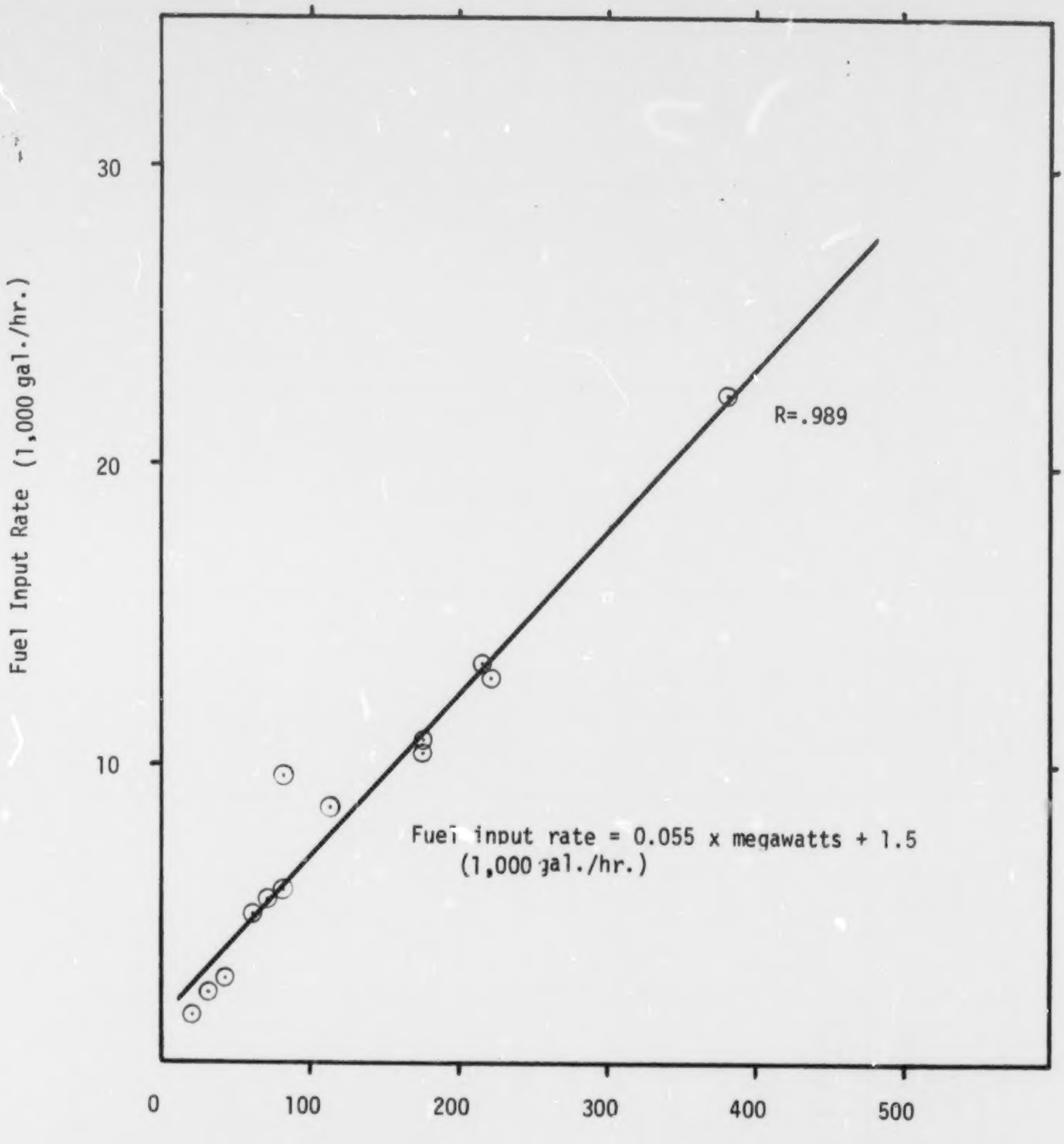

Figure II-3.1 Relationship of residual fuel oil requirements to electrical generating capacity.

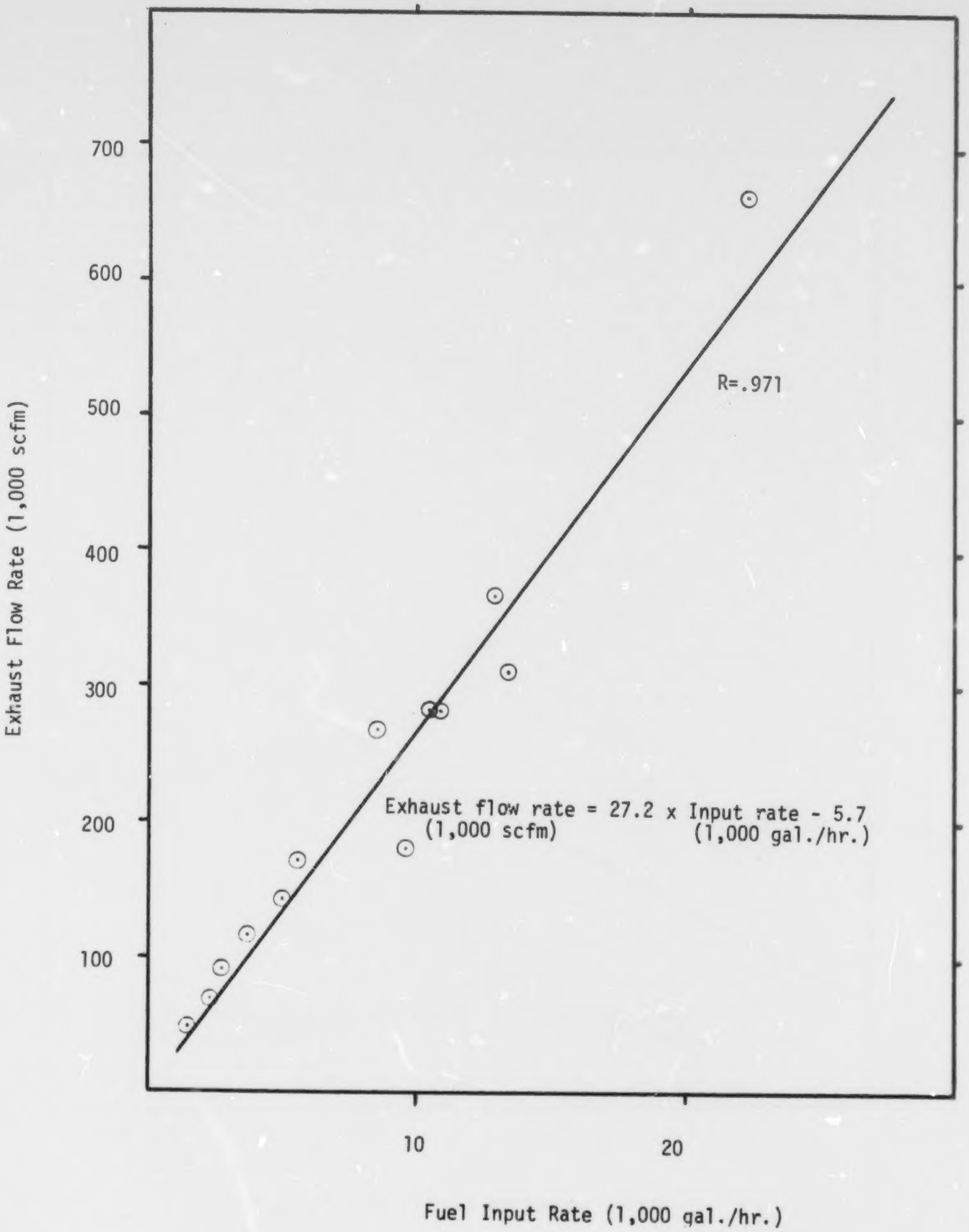

Figure II-3.2 Power plant exhaust gas flow rate vs. residual fuel oil input

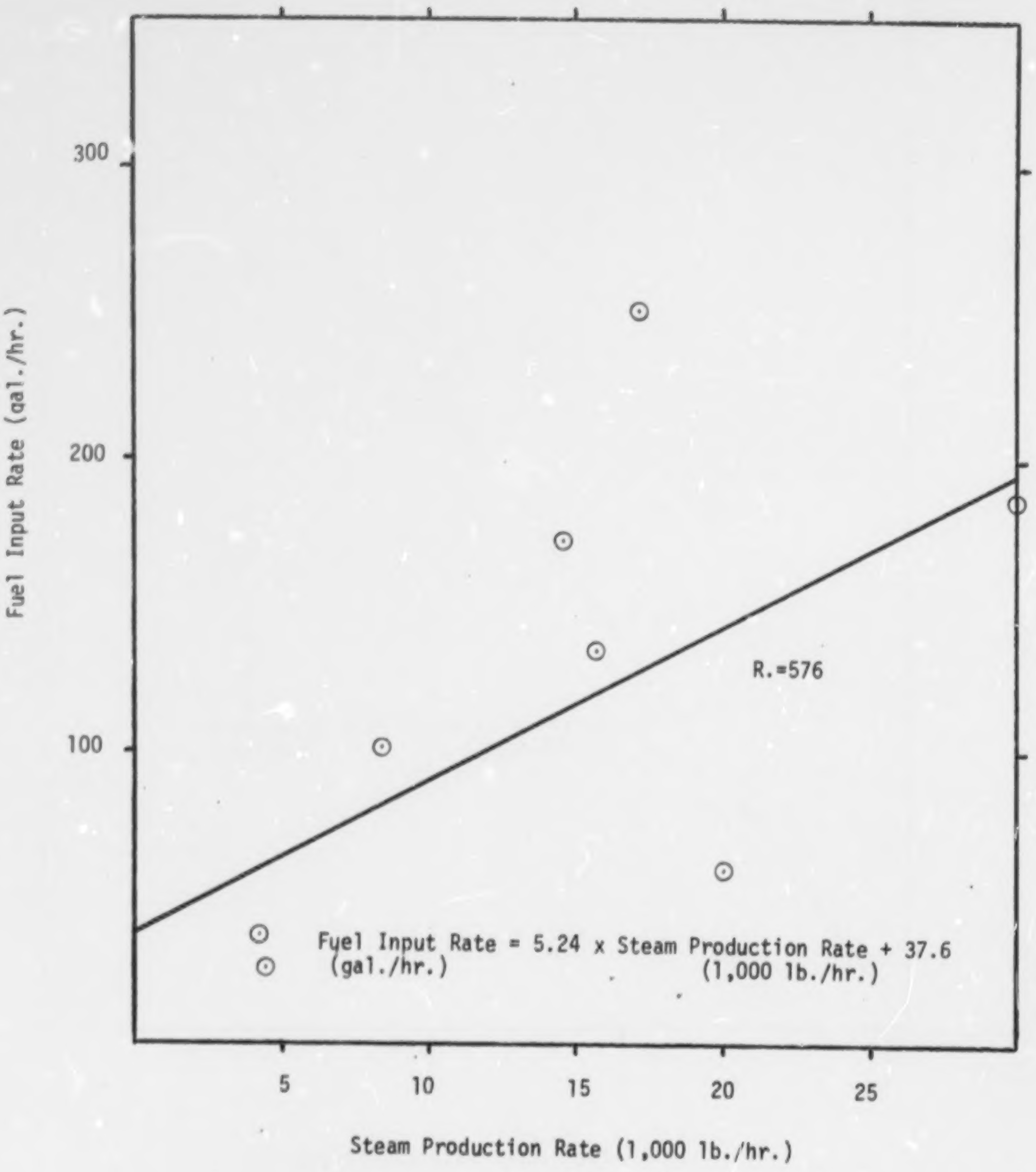

Figure II-3.3 Steam production rate vs. fuel oil input rate

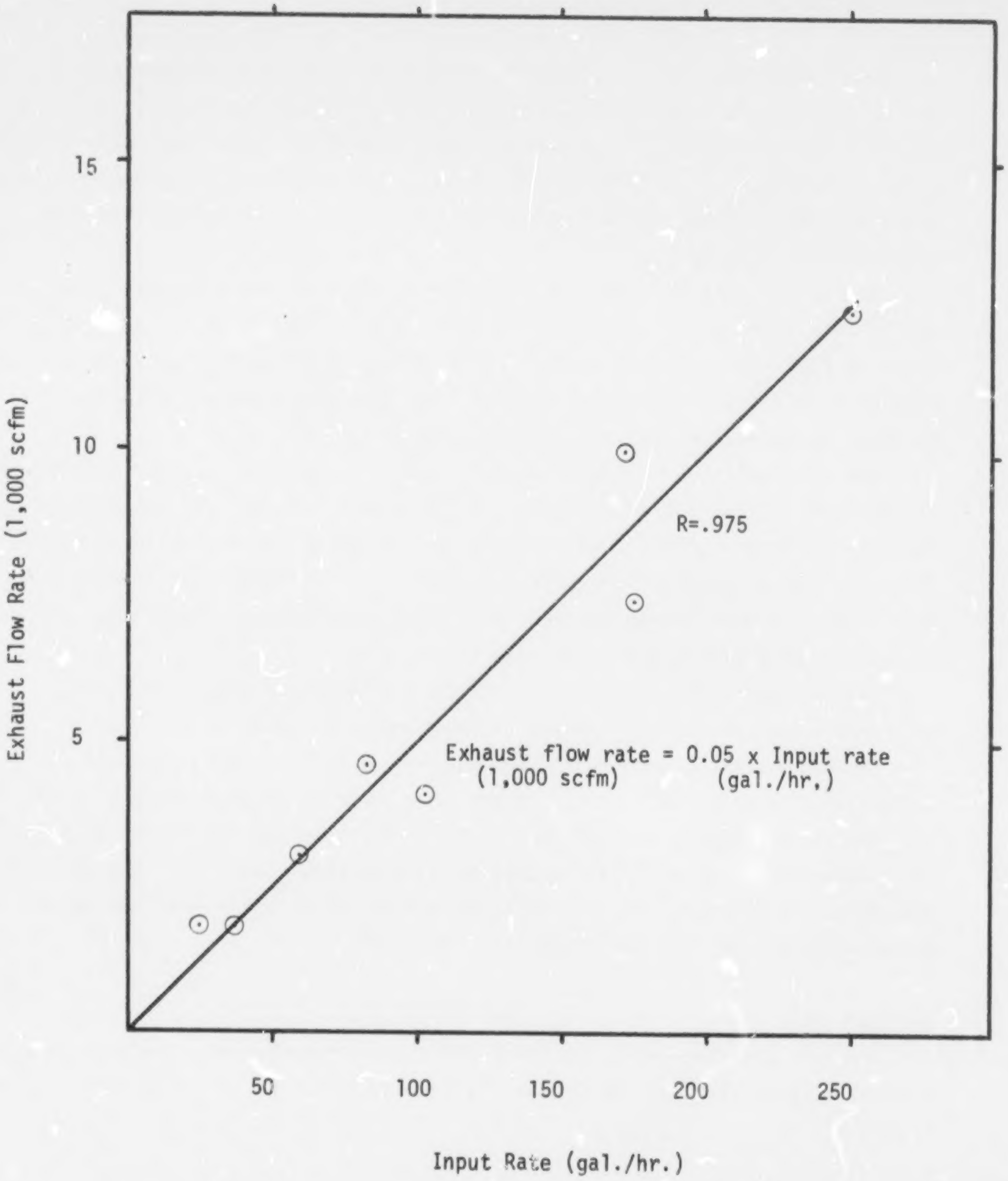

Figure II-3.4 Exhaust flow rates for small residual fuel oil units

CHAPTER II-4

DISTILLATE FUEL OIL COMBUSTION[B]

Distillate fuel oil is a light petroleum fraction, like kerosene or gas oil, resulting from the distillation, or topping, of crude oil. To provide standardization, specifications have been established for various grades of fuel oil.[32] Grades No. 1 and No. 2 are sometimes designated as light and medium domestic fuel oils. Table II-4.1 shows a typical analysis of distillate fuel oil.

Distillate fuel oil has several unique properties which enhance its use as a fuel for small combustion sources. Its viscosity, as compared to residual fuel oil, is low which results in smooth feed flow to the furnace without heat being added to the storage vessel or input lines. Also, it is lower in water, ash and other impurities.[33]

The heat value per pound of distillate oil is somewhat greater than residual oil (20,000 BTU/lb. for No. 1 versus 18,300 BTU/lb. for No. 6). Distillate fuel oil is more volatile than residual oil so combustion is simpler. Most furnaces using distillate oil have few combustion variables. The exhaust gas from these furnaces should not show wide variations because furnace manufacturers have preset most operating conditions.

Use of distillate oil shows an expected seasonal variation following the heating demand closely. Daily fluctuations also would be expected.

No air pollution control devices are used with distillate fuel oil fired furnaces or boilers. There seems to be wide variations in feed rates when data from Table II-4.2 are plotted with steam production (Figure II-4.1).[26] The reason given for the wide deviations is that these units are of a small capacity, are operated inefficiently (as can be noted by the high excess air rates of near 300%) and are intermittently fired.

GAS FLOW RATE

Exhaust gas flow rates for these units also showed wide variations when plotted (Figure II-4.2). An excess air rate of 65% would be considered typical.

GAS TEMPERATURE

Stack gas temperatures for 8 furnaces ranged from 240 to 500°F. For distillate oil fired units an average temperature of about 350°F should be used.

GAS VELOCITY

Based on discussions with two furnace manufacturers, a maximum velocity of 20 feet per second is anticipated.

STACK HEIGHT

Since most distillate oil is consumed in domestic or commercial furnaces, stack heights are expected to be on the order of 20 to 50 feet. An average of about 35 feet is expected.

TABLE II-4.1

Analysis of Grade No. 1 and Grade No. 2 Fuel Oils

Grade	No. 1 Fuel Oil	No. 2 Fuel Oil
Type	Distillate (Kerosene)	Distillate
Color	Light	Amber
API gravity, 60 F	40	32
Specific gravity, 60/60 F	0.8251	0.8654
Lb per U.S. gallon, 60 F	6.870	7.206
Viscos., Centistokes, 100 F	1.6	2.68
Viscos., Saybolt Univ., 100 F	31	35
Viscos, Saybolt Furol, 122 F	--	--
Pour point, F	Below zero	Below zero
Temp. for pumping, F	Atmospheric	Atmospheric
Temp. for atomizing, F	Atmospheric	Atmospheric
Carbon residue, per cent	Trace	Trace
Sulfur, per cent	0.1	0.4-0.7
Oxygen and nitrogen, per cent	0.2	0.2
Hydrogen, per cent	13.2	12.7
Carbon, per cent	86.5	86.4
Sediment and water, per cent	Trace	Trace
Ash, per cent	Trace	Trace
Btu per gallon	137,000	141,000

TABLE II-4.2

Exhaust Gases From Distillate Fuel Oil Combustion[26]

Production Rate 1000 lb. steam/hr.	Input Rate gal./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. ^{o}F	Excess Air %	Firing Mechanism
2.07	9.2	0.37	250	65	P.A.
3.45	6.3	0.48	290	290	P.A.
5.17	14.8	1.60	240	150	C.A.
6.90	21.2	1.89	360	210	C.A.
6.90	9.7	1.20	370	370	P.A.
10.35	23.2	1.23	390	115	C.A.
10.35	39.5	2.93	320	220	S.A.
12.75	86.2	3.97	500	94	C.A.

S.A. = steam atomization
C.A. = centrifugal atomization
P.A. = pressure atomization

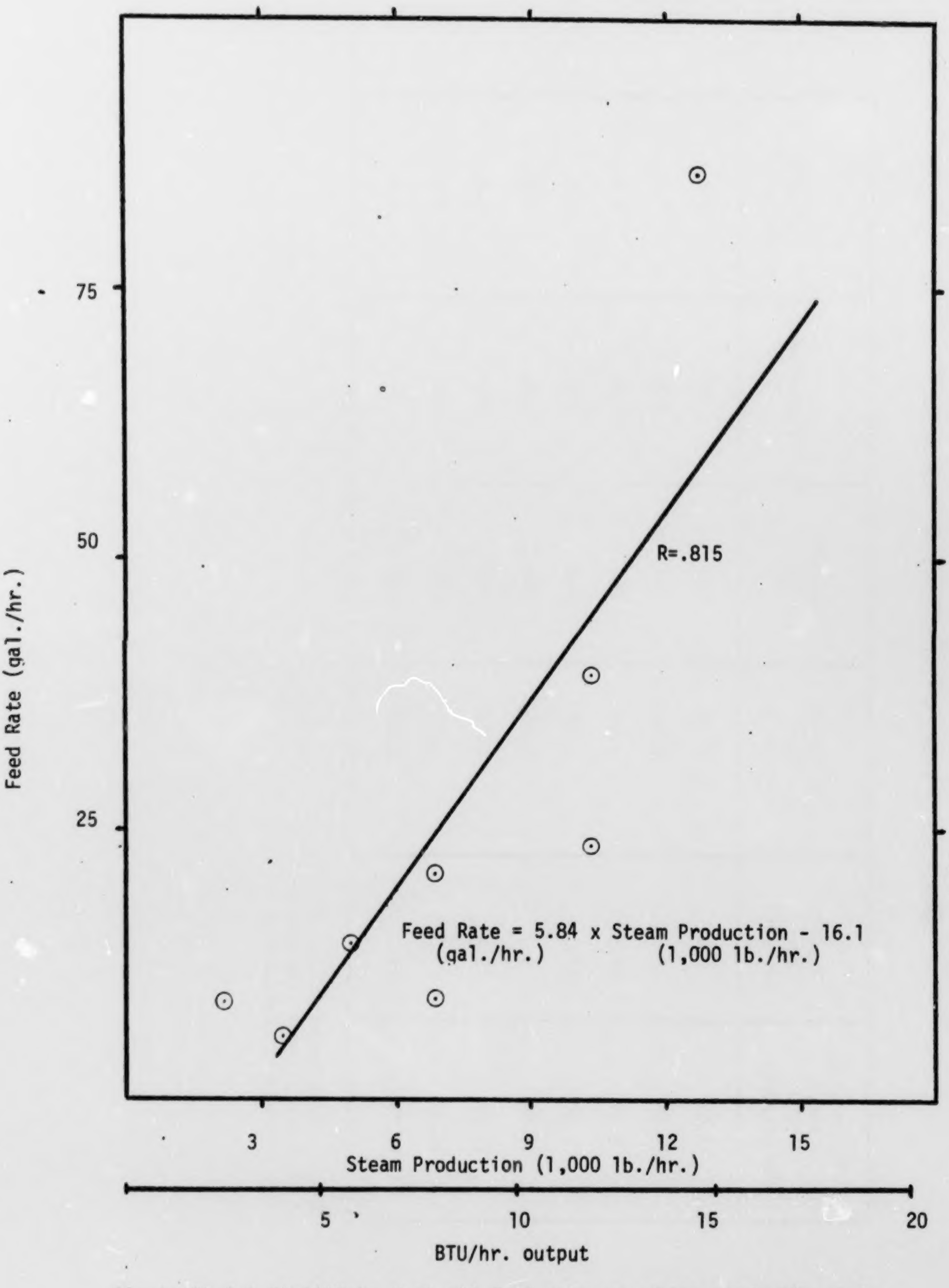

Figure II-4.1 Distillate fuel oil feed rate vs. steam production and heat output

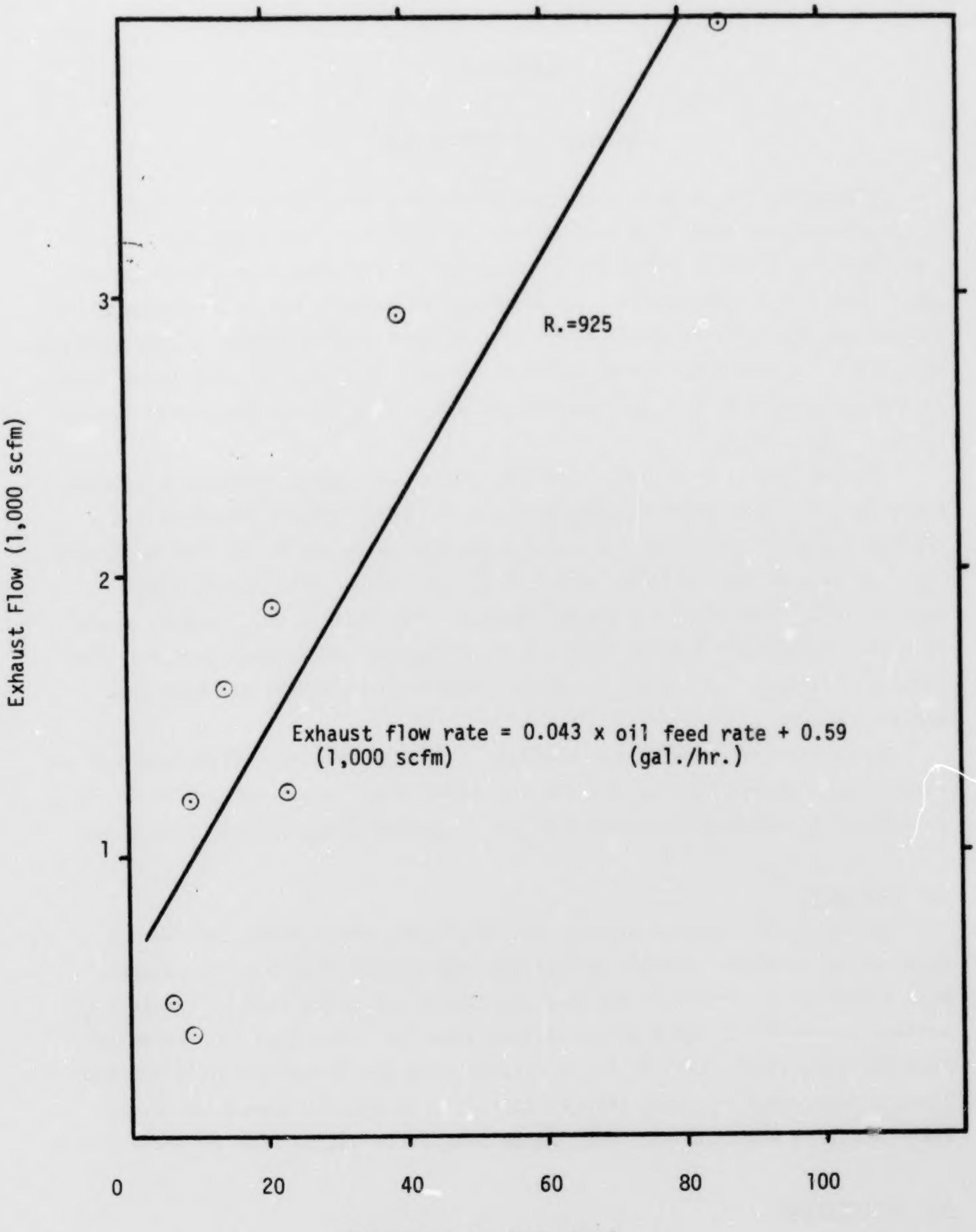

Figure II-4.2 Exhaust flow vs. feed rate in distillate fuel oil combustion

CHAPTER II-5

NATURAL GAS COMBUSTION[A]

Natural gas is perhaps the closest approach to an ideal fuel because it is practically free from non-combustible matter or solid residue. About one fourth of the electrical energy consumed in 1965 was produced by natural gas.[7] The trend today is for increased use of natural gas as an energy fuel because of its relative cleanliness. It is used predominately in the southwest and Pacific states where it is abundant and in large metropolitan areas where strict air pollution control regulations make other fossil fuels less attractive.

Natural gas is used for electrical power generation, industrial process steam and heat and domestic space heating.[32] Table II-5.1 illustrates the type of analyses available for various gas fields in the U. S. The mean heat value of natural gas is about 1050 BTU/cu. ft., and it does not deviate substantially from field to field. Because this fuel in its original state is a gas, it is homogeneous, thus making combustion operations simple. Fine tuning, utilizing low excess air rates, is possible because of these properties (Figure II-5.1).[31,33,34]

There are two types of gas burners: one which requires forced air and one which relies on atmospheric air for its combustion. A gas cooking stove is an example of an atmospheric air burner unit. Larger units require forced air.

GAS FLOW RATE

As mentioned earlier, natural gas is a homogeneous fluid thus making fine tuning possible. Common excess air rates range from 5 to 15 percent with a mean of 8 percent.[9] Because low excess air rates tend to reduce NO_x emissions, the trend today is to operate with low (less than 8%) excess air.[19] From the data (Table II-5.4) it is evident that operating variables are consistent from plant to plant (Figure II-5.2). In general lowest excess air rates would be expected with very large combustion units, such as power plants.

GAS TEMPERATURE

From the data collected, exhaust gas temperature ranged from 282 to 372°F with a mean of about 310°F which is slightly higher than coal or oil

oil fired units. Table II-5.3 is offered to show variations in temperature for large power plants.

GAS VELOCITY

The gas exit velocity ranged from 36 to 90 fps at the stack exit point. These velocities are typical of velocities from other large combustion facilities. The recommended velocity is 50 fps for these units when specific data is not available.

STACK HEIGHT

Typical stack heights and diameters are reported in Table II-5.2 for natural gas-fired power plants. Of course, different diameter stacks will result in different stack velocities; the diameter is apparently independent of plant size. For power plants, a stack height of 300 feet should be assumed. For industrial/commercial heating plants burning natural gas, a stack height of about 60 feet should be used. For residential users a stack height of 20 feet should be used.

TABLE II-5.1

Typical Composition of Natural Gas From Various Fields

(Monroe, Louisiana)

Methane	91.28
Ethane	1.52
Propane	0.70
Butane	0.41
Pentane	0.19
Hexane plus	0.15
CO_2	0.30
O_2	--
N_2	5.45
Higher heating value, BTU per cu ft, dry	997
Sp gr	0.6075

TABLE II-5.2

Plant Size, Stack Diameter and Stack Height For Natural Gas Fired Power Plants

	Plant Size 1000 lb. steam/hr.	Stack Diameter ft.	Stack Height ft.
	600	11	225
	850	13	225
	1,170	12	250
	2,000	22	450
	2,160	18	450
Avg.	1,356	15	320

TABLE II-5.3

Selected Exhaust Gas Temperatures For Natural Gas-Fired Units

Plant Capacity 1000 lb. steam/hr.	Temperature °F
600	358
850	340
5,300	249
2,000	269
2,160	253
3,316	282

TABLE II-5.4

Exhaust Gases From Natural Gas Combustion [31,33,34]

Production Rate Million lb. steam/hr.	Input Rate Million cfh.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity at Stack Cond. fps	Stack Height ft.	Stack Diameter ft.	Excess Air %
0.60	0.60	133	358	36	225	11	10
0.85	1.20	225	340	43	225	13	10
5.30	6.00	1,250	249	90	500	20	5
0.55	0.65	140	369	38	200	11	15
2.00	3.14	580	269	35	450	22	8
1.17	1.52	315	303	63	250	12	8
2.16	2.93	575	253	54	450	18	10
0.45	0.48	120	325				10
0.50	0.75	105	372				10
3.32	4.13	785	282				10

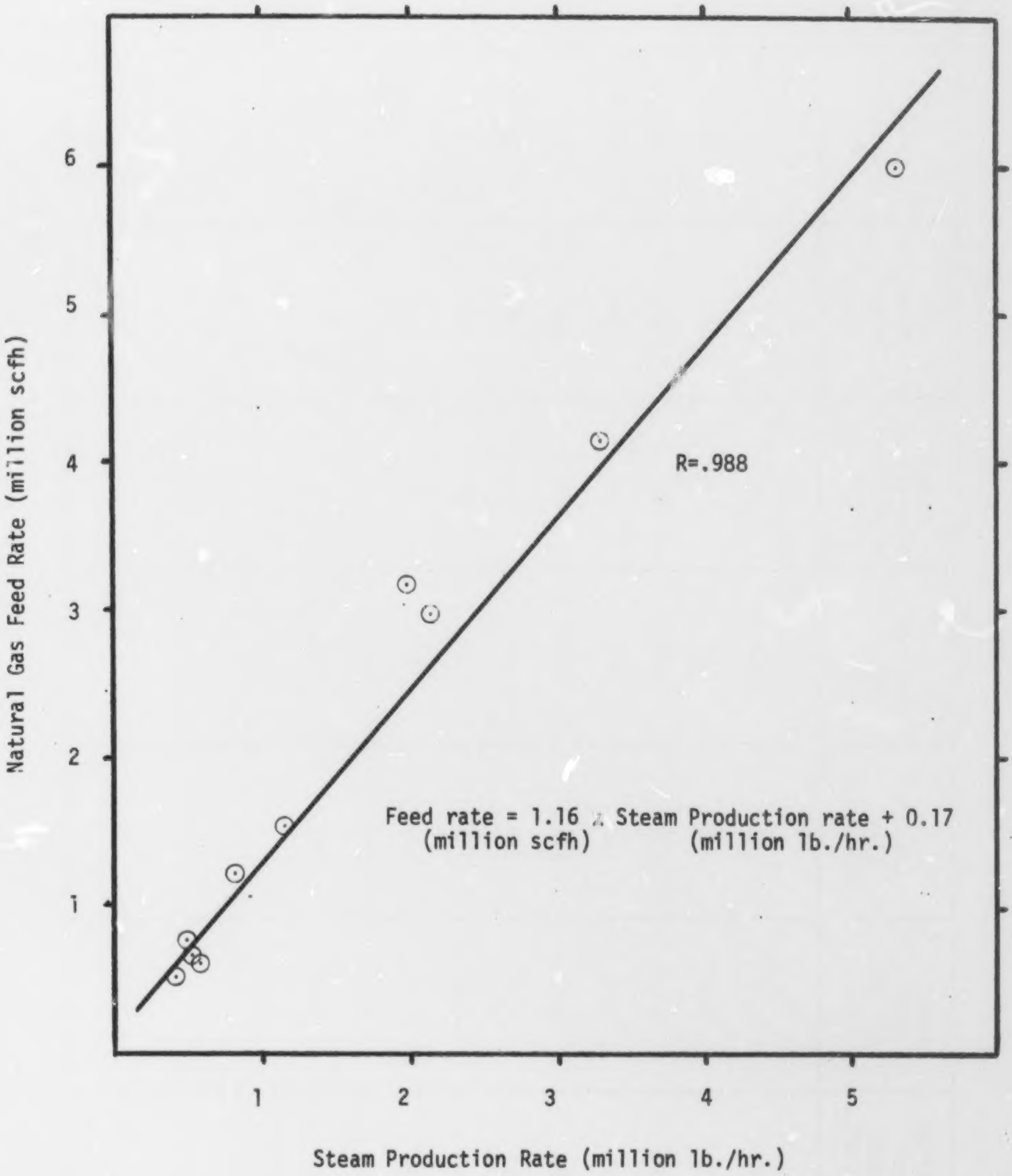

Figure II-5.1 Natural gas feed rate vs. different steam production rates

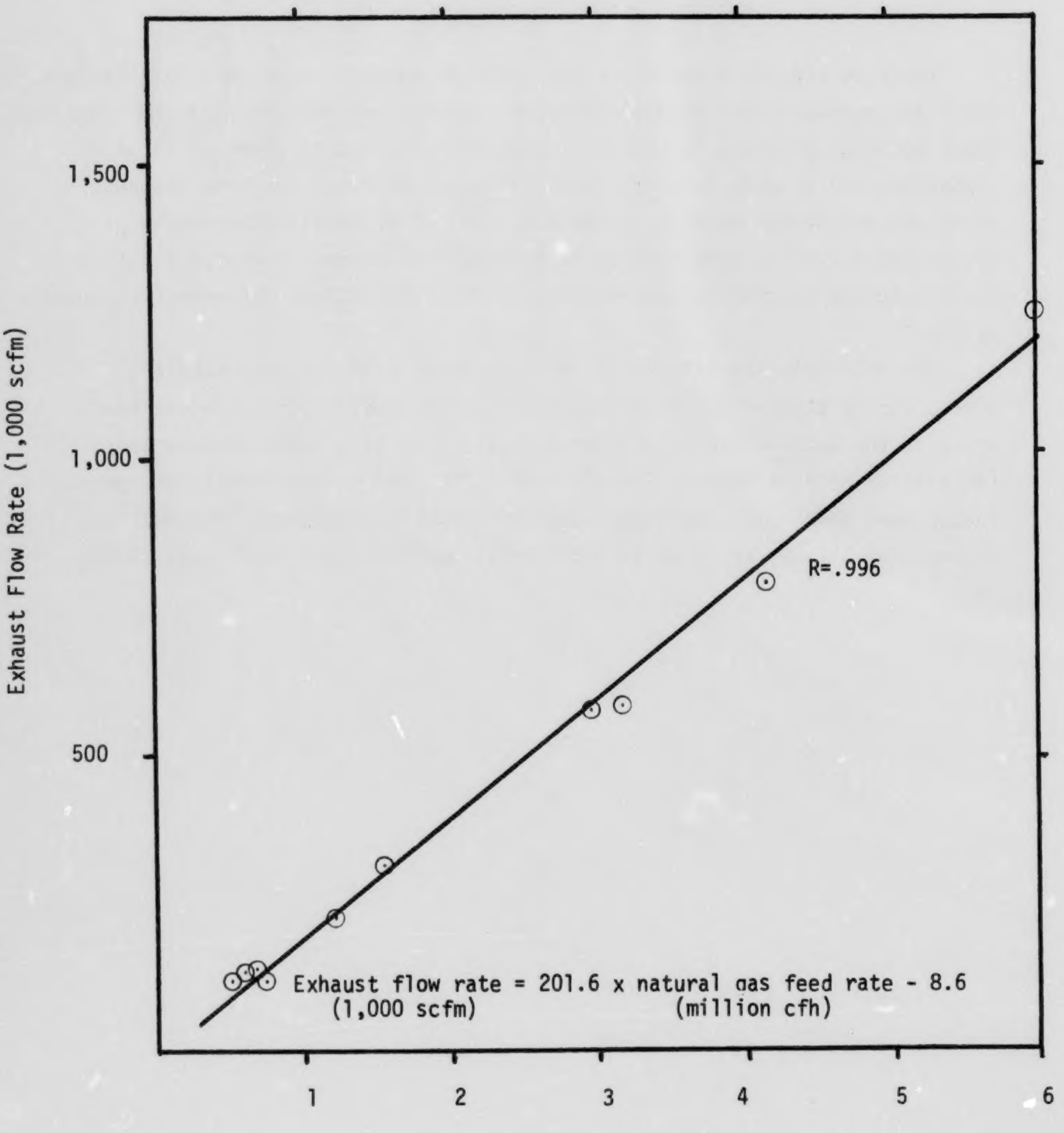

Figure II-5.2 Exhaust flow rates for natural gas combustion

CHAPTER II-6

LIQUIFIED PETROLEUM GAS COMBUSTION[c]

The term liquified petroleum gas, LPG, is applied to certain hydrocarbons which are gaseous under normal atmospheric conditions, but which can be liquified under moderate pressure at normal temperatures.[32] LPG is produced by oil refineries and is made up of the paraffinic series which includes propane, isobutane and normal butane. There are about 50 to 60 different types of LPG having different compositions of propane and butane. Table II-6.1 from the California Natural Gas Association (CNGA), illustrates the standard grades of LPG.[32]

The principle use for LPG is domestic heating in farm and mobile homes, curing tobacco and flame weeding. It is used as petrochemical feed stock in the manufacture of synthetic fibers (not as a combustion material). LPG also is used as an auxillary fuel with the less expensive natural gas during peak demand periods with connected commercial systems. The emission factors for LPG are the same as for natural gas described in Chapter II-5.

TABLE II-6.1

CNGA Standard Grade for LPG

CNGA Standard Grade	Max. Vapor Pressure Psig at 100 F	Range of Allowable Sp. Gr. 60/60 F H_2O = 1.0	Composition
A	80	0.585-0.555	Predominantly butanes
B	100	0.560-0.545	Butane-propane mixture, largely butanes
C	125	0.550-0.535	Butane-propane mixture, proportions approx. equal
D	150	0.540-0.525	Butane-propane mixture, propane exceeds butane
E	175	0.530-0.510	Propane-butane mixture, largely propane
F	200	0.520-0.504	Predominantly propane

CHAPTER II-7

WOOD WASTE COMBUSTION IN BOILERS[C]

Wood waste is mainly associated with the pulp and paper industry where refuse results from the separation of bark from the logs and the lumber industry where it appears mainly as shavings, sawdust and bark. One power plant in the state of Washington is reported to use it as a secondary (free) fuel with oil and natural gas.

Its value as a fuel is dependent on moisture content. The moisture content of freshly removed bark is high and may reach 75 to 80 percent.[32] Whenever bark exceeds 55 percent moisture, it is either pressed to remove the excess water or is mixed with drier material to give a product which can be burned. The analyses of wood refuse burned as a fuel are shown in Table II-7.1.[32] In comparison to coal, oil and gas, the more common boiler fuels, the carbon content of wood is low averaging only 55 percent.

Generally, wood waste boilers will need auxiliary fuels to provide a uniform steam output rate. A typical approach, therefore, is to use a spreader stoker type furnace with auxiliary fuels consisting of natural gas, coal or oil.

Larger boiler units operate on a continuous basis to supply steam while space heating applications would operate intermittently. Both tend to use whatever wood is available. When waste wood is plentiful one would expect the fuel mix to be about 80% wood and 20% oil.[35,36] Figure II-7.1 is a plot of the data listed in Table II-7.2.[35,36,37,38,39] Dry mechanical collectors including baghouses are the common type of collector used; however, most plants will not have any control devices.[37]

GAS FLOW RATE

The exhaust gas flow rate is plotted with heat input to the furnace since most units use auxiliary fuel (Figure II-7.2). No conclusion regarding excess air rates could be drawn from the data; however, 100% excess air can be considered typical. A flow rate of about 500 scfm can be expected for every million BTU/hr. of heat input.

GAS TEMPERATURE

The exhaust gas temperatures for 8 wood fired boilers ranged from 410 to 738°F, (Table II-7.2). An exit temperature of about 500°F would be considered average.

Mechanical collectors are the most common type of air pollution control device used for wood waste boiler systems. The temperature drop across these units varies with the collection system (e.g. 1 cyclone vs. 3 cyclones in series). An average temperature drop through each unit is about 10°F.

GAS VELOCITY

Not enough stack configuration data were available to calculate velocities for these units. However, an average gas velocity of 30 fps is typical for installations of similar BTU output capacity and excess air rates.

STACK HEIGHT

A review of the data for 15 boiler stacks at 6 pulp mills showed stacks to vary in height from steel stubs to 400 feet above ground.[35,37] A typical boiler stack height would be 250 feet.

TABLE II-7.1

Analyses of Wood Refuse Burned as Fuel

	Jack Pine	Birch	Maple	Eastern Hemlock
Proximate analysis, per cent				
Ash	2.1	2.0	4.3	2.5
Volatile	74.3	78.5	76.1	72.0
Fixed Carbon	23.6	19.2	19.6	25.5
Ultimate analysis, per cent				
Carbon	53.4	57.4	50.4	53.6
Hydrogen	5.9	6.7	5.9	5.8
Sulfur	0.0	0.0	0.0	0.0
Nitrogen	0.1	0.3	0.5	0.2
Ash	2.0	1.8	4.1	2.5
Oxygen (by difference)	38.6	33.8	39.1	37.9
Btu per lb (dry)	8930	8870	8190	8885
Ash analysis				
SiO_2	16.0	3.0	9.9	10.0
Al_2O_3	6.3	0.0	3.8	2.1
Fe_2O_3	5.0	2.9	1.7	1.3
CaO	51.6	58.2	55.5	53.6
$CaCO_3$	4.9	13.0	1.4	9.7
MgO	5.5	4.2	19.4	13.1
MnO	1.6	4.6	1.0	1.2
P_2O_5	2.8	2.9	1.1	2.1
K_2O	4.1	6.6	5.8	4.6
Mn_2O	3.1	1.3	2.2	1.1
TiO_2	0.2	Trace	Trace	Trace
SO_3	2.6	3.2	1.4	1.4
Fusion point of ash, F				
Initial	2450	2710	2650	2760
Softening	2750	2720	2820	2770
Fluid	2760	2730	2830	2780
Weight, lb per cu ft, bone dry	29	37-44	31-42	26-29

TABLE II-7.2

Exhaust Gases From Wood Waste Combustion [35,36,37,38.39]

Production Rate lb. steam/hr.	Input Rate lb./hr.	Exhaust Flow scfm	Exhaust Temp. °F	Excess Air %
	150	420		
	350	557		
	750	3260		
	1000	3300		
	3000	15300		
280,000	95255	96400	420	20
Heat input million BTU/hr.				
6	900	2720		100
228			460	
408			738	
457			420	
407			410	
457			455-475	
456			640	

TABLE II-7.2

Exhaust Gases From Wood Waste Combustion [37,38] (continued)

Production Rate 1000 lb. steam/hr	Input Rate million BTU/hr	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Excess Air %
230	150	85		
400	262			
410	270	120		
405	275	115		
450	305	140		
455	298	125		
465	300			
455	305	130		

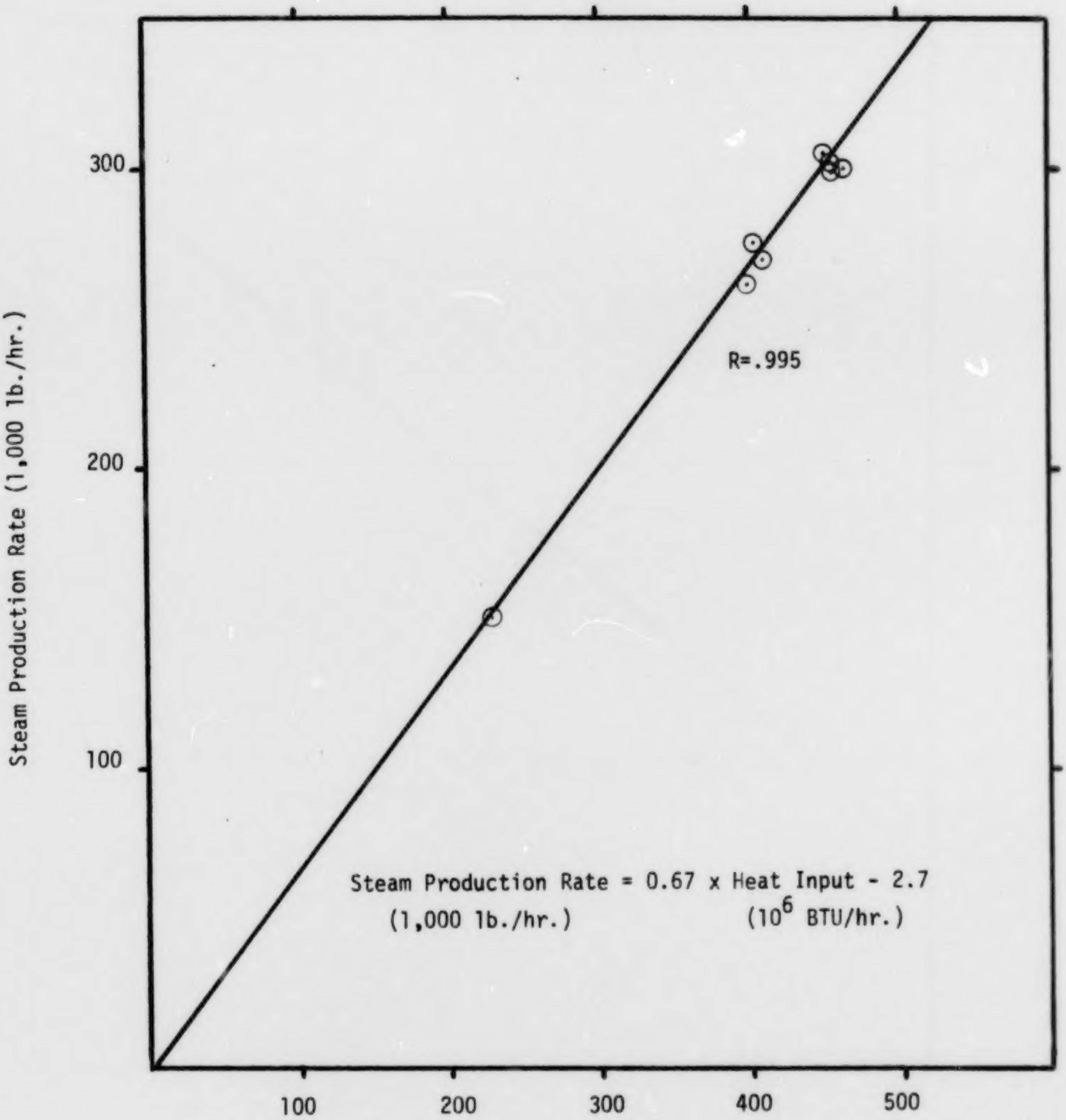

Figure II-7.1 Input vs. output for wood waste combustion units

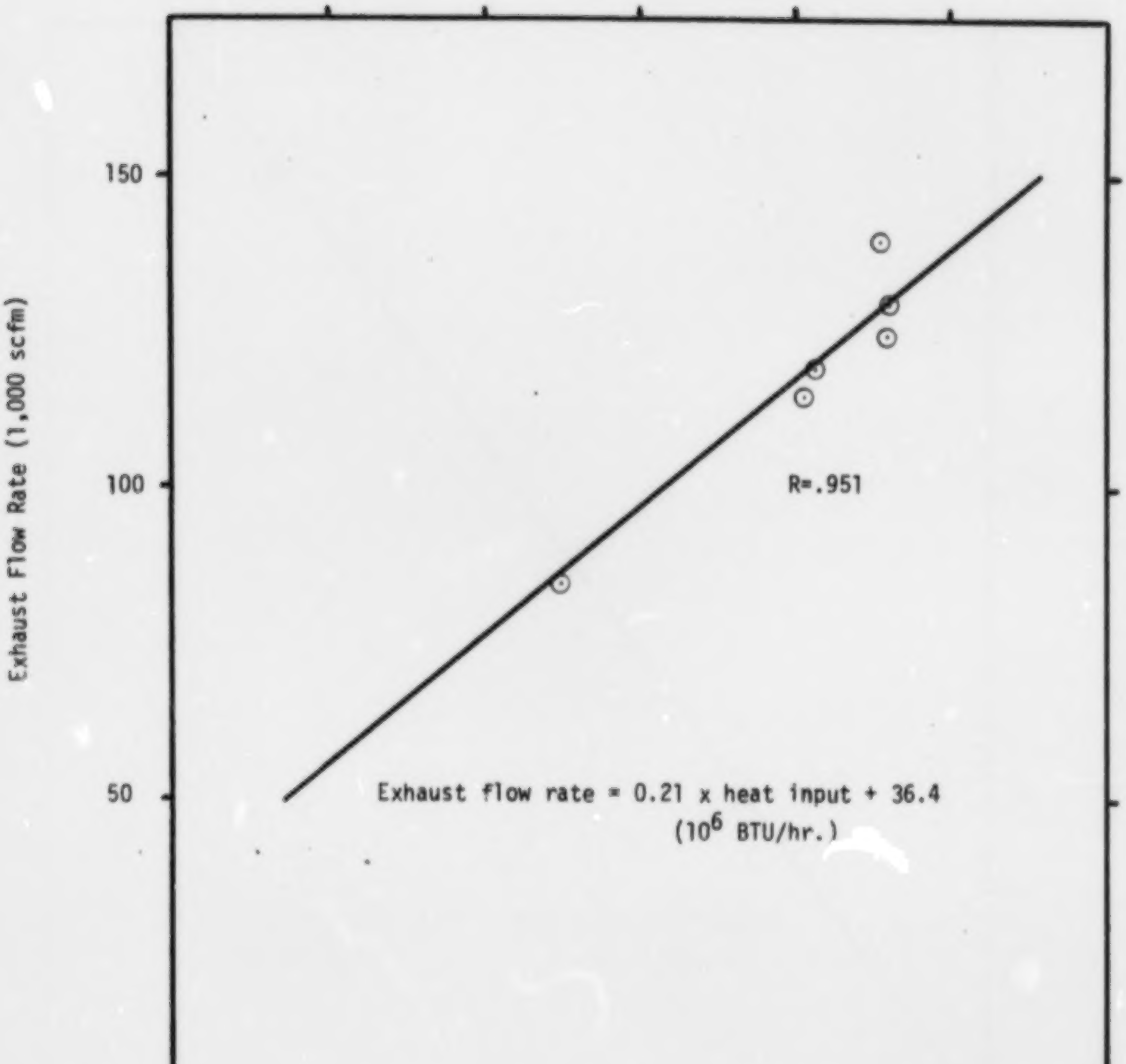

Figure II-7.2 Exhaust gas flow rates for wood waste combustion units

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CHAPTER III-1

MUNICIPAL INCINERATION[A]

Municipal incineration is frequently termed "central incineration" since burning of refuse is carried out at one or perhaps a few strategic locations in a community. Municipal incinerator capacities typically range from 50 to 500 tons per day (4,000 - 40,000 lb./hr.). Small cities may have oversized incinerators to allow for growth and so may operate only 8 hours a day; shifts are added as the amount of refuse increases. Incinerators in larger cities commonly operate around the clock for 5 or 6 days a week. Chicago, Miami, Louisville, and Atlanta operate incinerators continuously 7 days a week. A survey of 64 plants disclosed that 85 percent were designed to operate for two or three shifts per day and for 5 to 6 days per week.[6]

A typical refuse composition analysis is provided in Table III-1.1. For a given community the largest variations in refuse composition are noted in the increased paper around Christmas time and the increased yard wastes during the summer and fall months.

Because most municipal incinerators are located in densely populated areas which have air pollution ordinances, almost all municipal incinerators will have pollution abatement equipment. Large units, greater than 20 tph, are built with water spray chambers and wet baffles to control particulates. The trend today is toward larger furnaces, with total capacities of 1000 tpd, having the best available control equipment. This includes wet scrubbers and electrostatic precipitators most of which have only recently been installed on these incinerators in North America.

GAS FLOW RATE

Three important variables affecting incinerator exhaust gas flow are refuse heating value, excess air (% of stoichiometric air), and quantity of water evaporated in conditioning and cooling exhaust gases.

As heating value of refuse increases, so does incineration efficiency and exhaust gas flow rate. The higher heating value (dry basis) of several substances commonly found in municipal refuse and of typical refuse itself is presented in Table III-1.2. The heat contents (dry) of municipal refuse from several cities (Table III-1.3) show relatively consistent values because of the averaging effects of the large population served. Non-combustible materials such as bottles, cans, ash, etc. serve to reduce the average heating value of mixed refuse below the values shown in Table III-1.3. Where heating values are not known for a specific incinerator, it is suggested that 4,450 BTU/lb. refuse (wet) be used since this figure was derived from a recent comprehensive field survey.

Organic materials, the principal group of combustible components of municipal refuse, theoretically require about 0.7 lb. of combustion air per 1,000 BTU under stoichiometric conditions.[6] The data of reference 3 yield a value of 0.72 lb. of stoichiometric air per 1,000 BTU. These same data indicate that flue gas volume exceeds combustion air volume by about 30% for stoichiometric combustion. Making use of these two approximations, a series of curves was prepared to show stack gas flow as a function of refuse heating value at various excess air levels. (Figure III-1.1)

Excess air values range from 100 to 400% with most refractory lined municipal incinerators operating at about 200% ($<5\%$ CO_2). On the other hand, water-walled municipal incinerators operate at about 50% excess air. The Incinerator Institute of American standards require a design minimum of 150% excess air for refractory lined municipal incinerators so lower excess air rates are very unlikely.[5] If the excess air level is not available directly from the individual sources, a value of 200% should be used for estimating flue gas flow rates.[1,2,3]

Water sprays, scrubbers, or wetted baffles are frequently used for cooling and cleaning incinerator exhaust gas. The effect of evaporated water on stack gas flow is shown in Figure III-1.2, based on data from reference 3 for 4,450 BTU/lb. refuse. With 200% excess air being utilized, and 2.0 lb. of water being evaporated per pound of refuse, the stack gas flow of 2.3 scfm/ (lb. refuse/hr.) is increased to 3.0 scfm/ (lb. refuse/hr.) under these conditions.

Exhaust flow rates of several municipal incinerators are shown in Table III-1.4 and plotted in Figure III-1.3. Figure III-1.1 may be used when specific data, such as refuse heating value, excess air rate, and refuse input rate are available for the municipal incinerator.

GAS TEMPERATURE

Histogram plots of stack gas temperature data for 10 municipal incinerators without evaporative gas cooling and 16 with evaporative gas cooling are shown as Figure III-1.4. Based on these observations, stack gas temperatures from non-water-cooled incinerators are chiefly in the range, 700 - 950°F. Temperatures of gases from water cooled systems lie predominately in the range, 400 - 600°F. For dispersion calculations, investigators should use 500°F for incinerators with evaporative cooling and 800°F for incinerators without evaporative cooling.

GAS VELOCITY

Stack dimensions are commonly set by design to provide an exhaust velocity less than 30 fps at the emission point when the incinerator is operating at design rate.[7] A velocity of 25 fps has been used by some designers and should be used for dispersion calculations where actual values are unavailable. If the top stack cross-sectional area is known, the exhaust gas velocity can be calculated from the actual gas volume flow rate.

STACK HEIGHT

Municipal incinerator stack heights range from 50 to 250 feet. When specific point source data is unavailable, use 150 feet.

TABLE III-1.1

Typical Composition of Municipal Refuse[3]

CATEGORY	PERCENT BY WEIGHT
Glass	8.4
Metal	8.2
Paper	35.8
Plastics	1.3
Leather, Rubber	1.4
Textiles	1.9
Wood	2.3
Food Wastes	18.7
Miscellaneous	1.6
Yard Wastes	20.4
	100.0

TABLE III-1.2

Typical Heating Value of Various Substances[1,3,4]

SUBSTANCE	HEATING VALUE (BTU/dry lb.)
Wood Sawdust (oak)	8,493
Wood Sawdust (pine)	9,512
Rags (wool)	8,876
Rags (cotton)	7,165
Cardboard	5,970
Newspaper	7,883
Lard	16,740
Garbage	7,300
Refuse	6,250
Refuse	6,195

TABLE III-1.3

Typical Heating Value of Municipal Refuse[14,16]

LOCATION	HEATING VALUE (BTU/dry lb.)
Washington, D. C.	6,336
Norfolk, Va.	5,000
Chicago, Illinois	5,000
Typical	5,395

TABLE III-1.4

Exhaust Gases from Municipal Incineration [17]

Input Rate tph	Exhaust Flow 1000 scfm	Exhaust Temp. °F.	Stack Height ft.	% CO_2	% Excess Air
18.87	67.7	641	175	3.58	>200
16.08	63.6	706	↓	4.58	↓
17.37	64.7	716	↓	3.56	↓
13.48	65.8	730	↓	3.87	↓
16.37	65.6	728	↓	3.77	↓
11.52	65.7	738	↓	3.70	↓
15.42	65.6	714	↓	3.53	↓
17.60	65.4	725	↓	3.69	↓
11.38	66.2	730	↓	3.38	↓
12.48	66.0	737	↓	3.87	↓
16.57	66.4	751	↓	3.21	↓
19.35	66.4	670	175	3.72	>200
14.70	66.4	642		3.67	
14.82	66.6	674		3.66	
13.50	65.2	679		3.96	
13.54	56.5	672		3.29	
15.95	67.2	702		3.58	
16.0	54.0	410			
8.5	30.0	250			
5.3	24.8	710			
5.0	21.1	680			

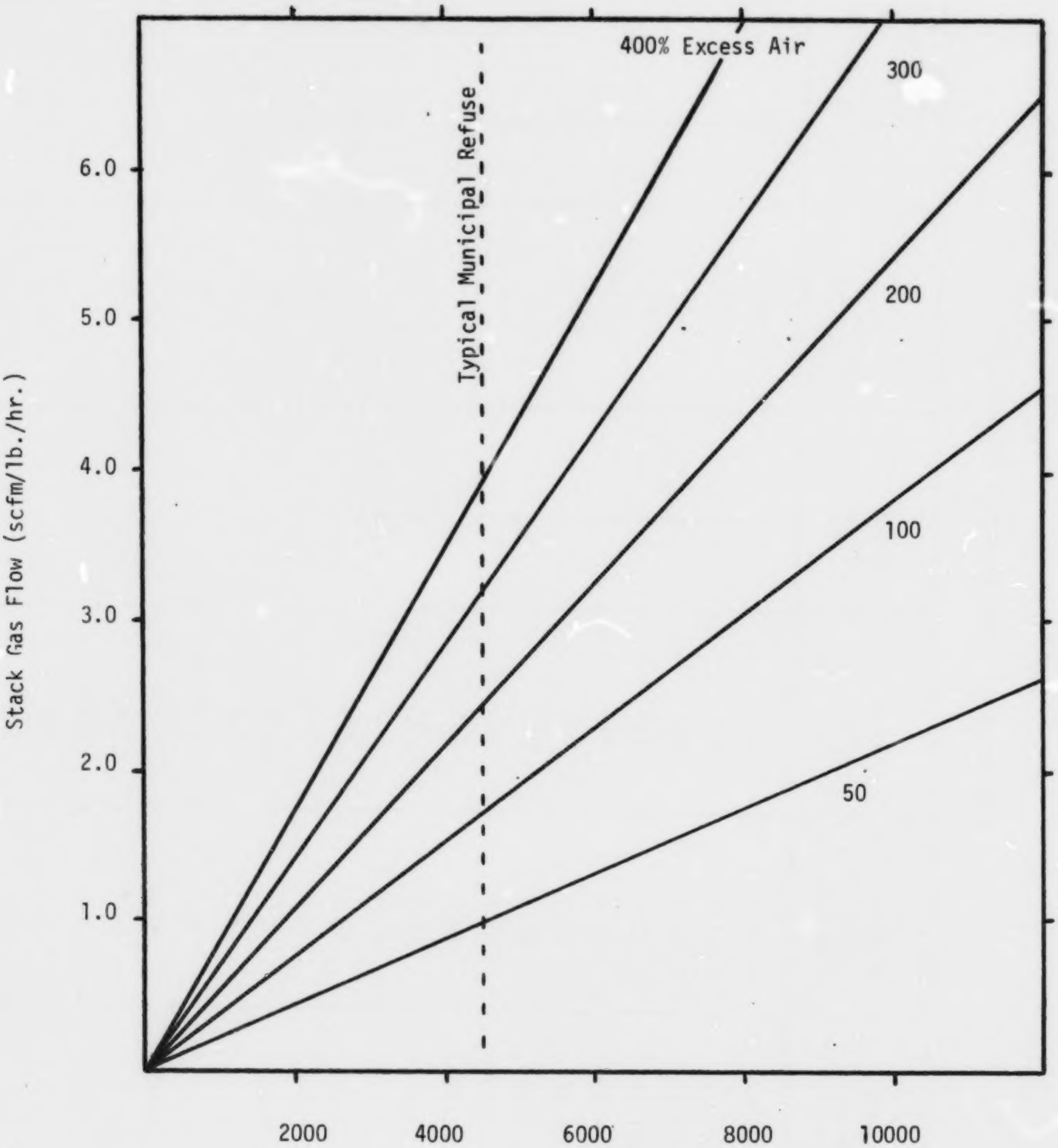

Figure III-1.1 Effect of refuse heating value on exhaust flow rate for different excess air levels.

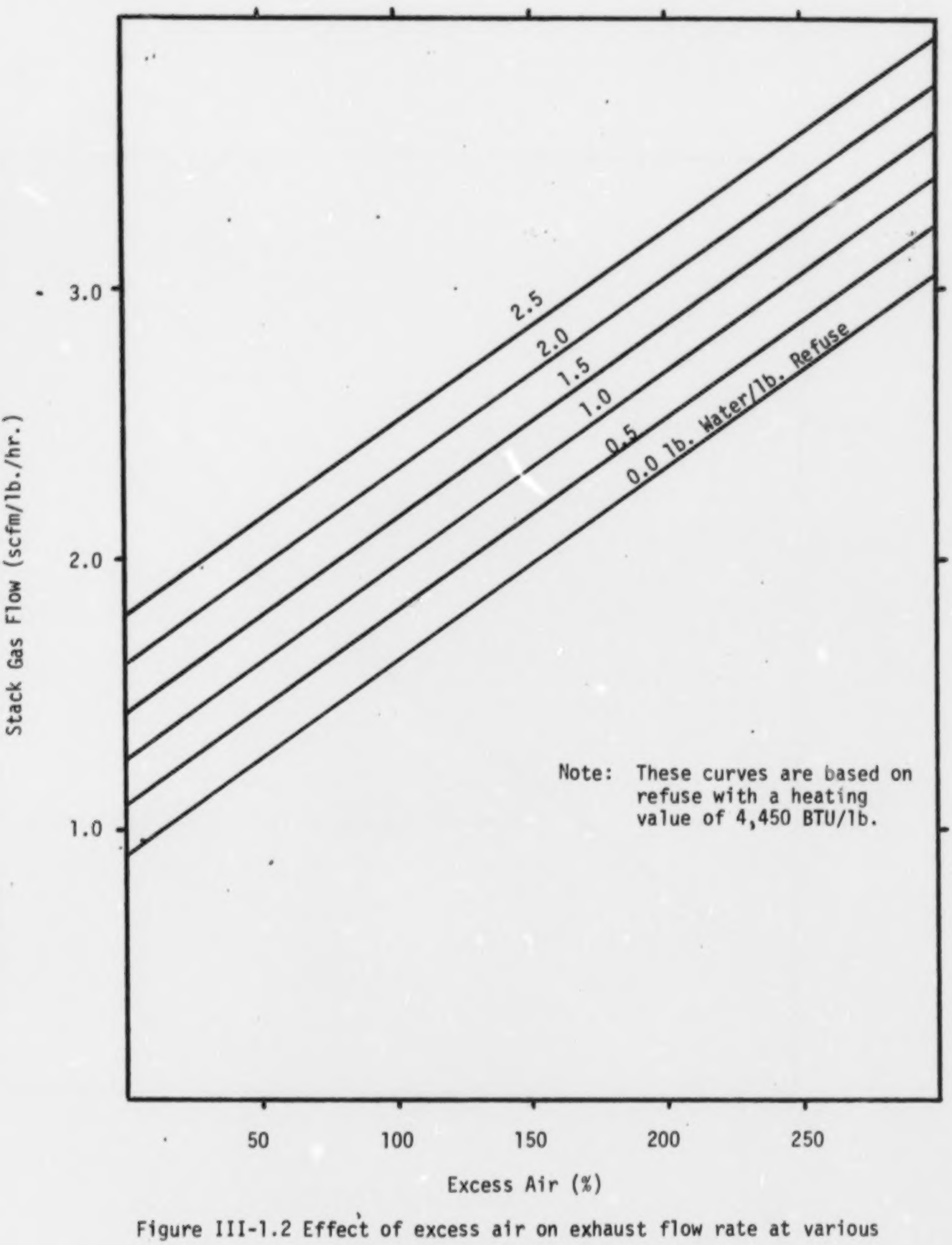

Figure III-1.2 Effect of excess air on exhaust flow rate at various evaporative cooling rates.

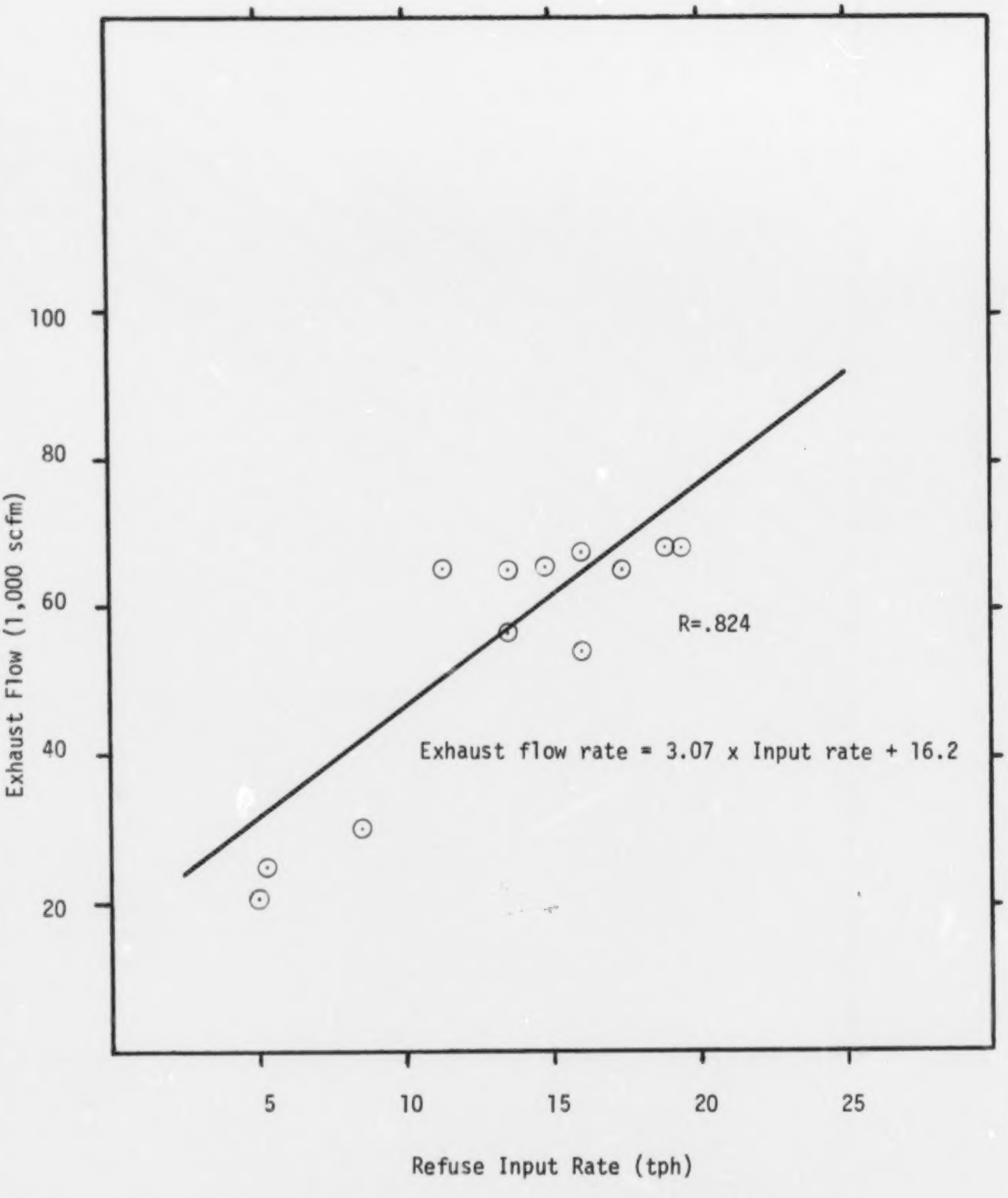

Figure III-1.3 Exhaust flow rates for municipal incinerators.

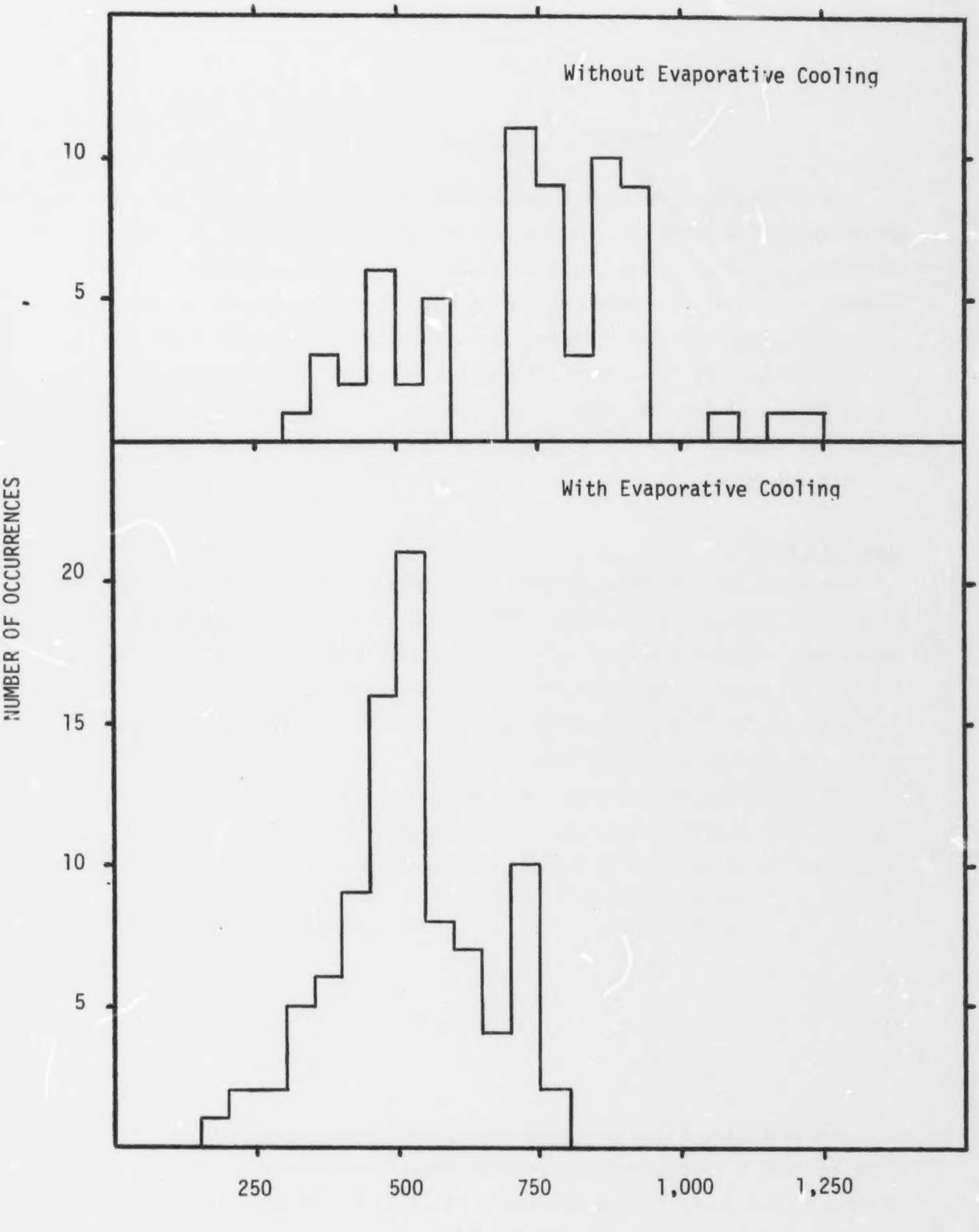

Figure III-1.4 Frequency distribution of exhaust gas temperatures for municipal incinerators

CHAPTER III-2

INDUSTRIAL/COMMERCIAL INCINERATION[A]

In contrast to central incineration where refuse is carried from remote sites to the incinerator, industrial and commercial refuse is generally incinerated at or near its point of origin. For this reason, it is called on-site incineration. Typical sizes range from 50 to 2,000 lb./hr. capacity.

Operating times for industrial/commercial incinerators vary widely, but the Incinerator Institute of America suggests that maximum operating times should be no more than 7 hours of operation per shift for industrial units and 6 hours of operation per day for commercial buildings, institutions and hotels.[5]

GAS FLOW RATE

Industrial/commercial refuse is generally very specific to a particular location, and quite large differences in the heating values may be observed. In addition, use of auxiliary fuel with refuse of low heating value can further complicate the situation. Because of these factors, it is generally more straightforward to treat such waste on a BTU/hr. basis rather than a lb./hr. basis.

If auxiliary fuel firing rates are unavailable, the Incinerator Institute of America standards recommend that auxiliary fuel inputs tabulated below be used in combustion gas volume calculations:[5]

Refuse as Fired BTU/lb.	Auxiliary Fuel BTU/lb. of Refuse
4300	0
2500	1500
1000	3000

Exhaust flow rates per 1000 BTU/hr. of total firing were calculated from several sets of incinerator test data [6] (Table III-2.1). These observed data were plotted in Figure III-2.1 to provide comparison with predicted values shown by the straight line.

The approximations made in the presentation of exhaust flow rate as a function of refuse heating value for municipal incineration (Figure III-1.1) are valid for other refuse as well if the burnable part of such refuse is largely organic matter. Figure III-2.1 shows the predicted relationship of stack gas flow (scfm/(1000 BTU/hr.) to excess air based on a cross-plot of the data from Figure III-1.1. The stack gas flow per unit of heating value is seen to be a function only of the excess air utilized.

From Table III-2.1, the refuse heating value ranged from 5,270 BTU/lb. to 7,660 BTU/lb. and use of auxiliary fuel ranged from 0 to over 3 million BTU/hr. heat input. Heating values may be determined if the waste analysis is known. Otherwise assume 7,000 BTU/lb. for the waste and 1 million BTU/hr. for auxiliary fuel input. Figure III-1.1 also may be used for industrial/commercial incinerators.

The Incinerator Institute of America standard for Class III multiple-chamber incinerators suggests the use of 100 percent of excess air for gas velocity calculations.[5] The average reported value for excess air levels from Table III-2.1 was 113 percent which shows good agreement. If actual values are not available, assume 100 percent excess air and stack gas flow rates of 0.31 scfm/(1000 BTU/hr.) heat input.

GAS TEMPERATURE

The temperature data of Table III-2.1, for incinerators without water cooling of the exhaust gases, have an average value of 1210°F. This is considerably higher than the usual temperature range of 700 - 950°F for municiple incinerators, but the higher the BTU/lb. content of the refuse, the use of auxiliary fuel, and the higher heat release rates probably account for much of this difference. For design purposes, the Incinerator Institute of America suggests the use of 1400°F for calculating exhaust gas velocities, but this figure is deliberately chosen higher than the expected values to allow a margin of safety in the sizing of gas ducts. When temperature data are not available, 1200°F should be used for calculations.

GAS VELOCITY

If the stack cross-sectional area and the exhaust flow (acfm) are known, exit gas velocity can be calculated. Most industrial/commercial incinerators use natural draft stacks between 12" and 36" in diameter. With 100 percent excess air, exhaust temperature of 1200°F, stack diameters recommended by IIA and gas flow rates from Figure III-1.1, stack gas velocities can be calculated as a function of refuse firing rate for different types of refuse. The results of such calculations are shown in Figure III-2.2. If velocity cannot otherwise be obtained or calculated, 20 fps should be used for dispersion calculations.

STACK HEIGHT

Recommended stack heights shown in Table III-2.2 may be used in the absence of specific data. In many cases height of other buildings, etc. will set the stack height. When no information can be obtained, 40 feet should be used for stack height in dispersion calculations.

TABLE III-2.1

Exhaust Gases From Industrial/Commercial Incinerators[6]

Test No.	Refuse lb/hr	Refuse Btu/lb[a]	Firing Rate (1000 Btu/hr) Refuse	Firing Rate (1000 Btu/hr) Fuel[b]	Firing Rate (1000 Btu/hr) Total	SCFM	SCFM/(1000 Btu/hr)	Excess Air (%)[c]	Temperature (^oF)
1a	47	6450	303	0	303	174	0.57	117	1160
1b	46	5270	242	363	605	193	0.32	37	1475
2	150	7660	1150	0	1150	420	0.36	96	1020
3	185	6210	1050	1080	2130	480	0.23	22	1600
4a	350	7660	2680	0	2680	557	0.21	110	1140
5	113	5900	4200	1240	5440	1970	0.36	140	910
6	870	5800	5050	3140	8190	2190	0.27	83	1560
8	940	7660	7200	0	7200	3200	0.44	230	1000
9	1068	7660	8180	0	8180	3300	0.40	174	1160
10	820	6450	5290	1530	6820	2700	0.40	190	1080
11a	1055	7660	8090	0	8090	2200	0.27	65	--
11b	700	7660	5360	0	5360	2130	0.40	114	--

a. Calculated from refuse composition.
b. Natural gas assumed to have higher heating value of 1100 Btu/SCF.
c. Calculated from Orsat stack gas analysis by means of equation II-4.

TABLE III-2.2

Recommended Stack Heights and Internal Diameters for Class III Natural Draft Incinerators[5]

Capacity (lb/hr)	Type 0 Refuse[(a)] Diameter (in.)	Type 0 Refuse[(a)] Height (ft.)	Type 1 Refuse[(b)] Diameter (in.)	Type 1 Refuse[(b)] Height (ft.)	Type 2 Refuse[(c)] Diameter (in.)	Type 2 Refuse[(c)] Height (ft.)
100	16	30	14	30	12	25
150	18	30	16	30	14	30
200	20	35	18	35	16	30
300	22	35	20	35	18	35
400	24	40	22	40	20	40
500	26	40	24	40	22	40
600	28	40	26	40	24	40
700	30	45	28	45	26	45
800	32	45	30	45	28	45
900	34	45	32	45	30	45
1000	36	45	34	45	32	45

a. Trash. As fired higher heating value = 8500 Btu/lb.
b. Rubbish. As fired higher heating value = 6500 Btu/lb.
c. Refuse. As fired higher heating value = 4300 Btu/lb.

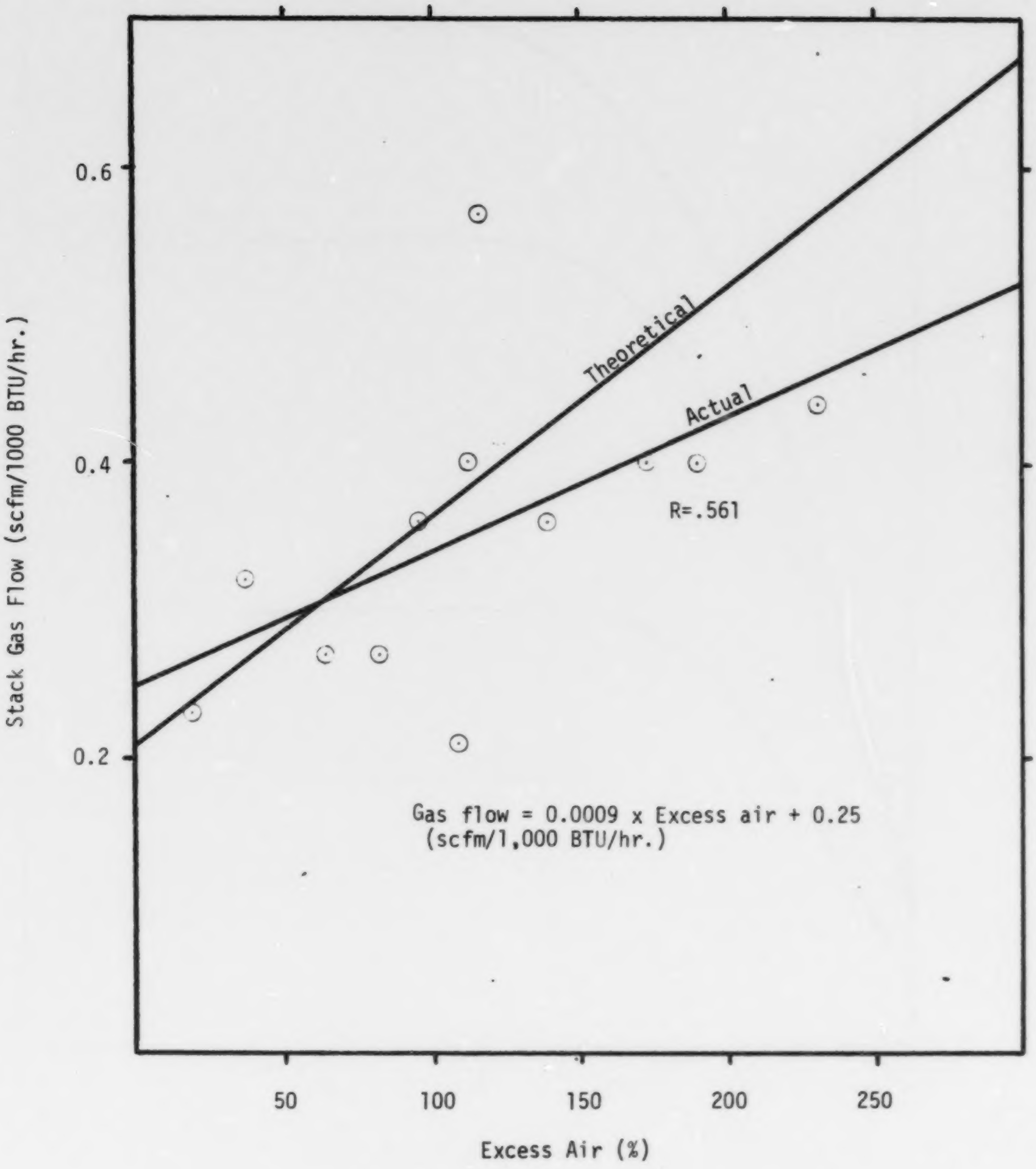

Figure III-2.1 Comparison of measured stack gas flow with predicted stack gas flow for industrial/commercial incinerators

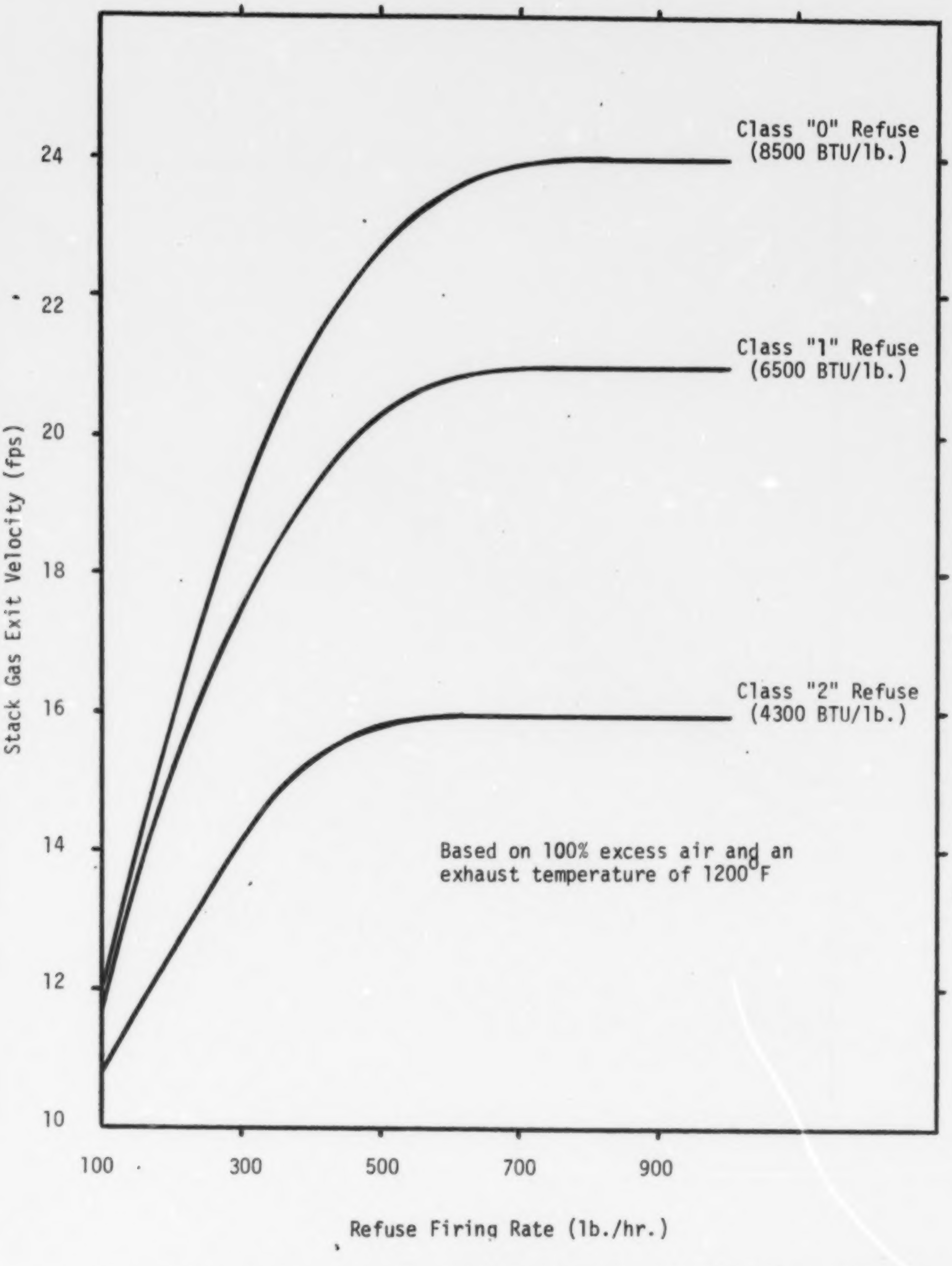

Figure III-2.2 Design stack velocities for Class III (multiple chamber) refuse incinerators with natural draft exhaust

CHAPTER III-3

DOMESTIC INCINERATION[A]

As used here, the term "domestic incineration" refers to the on-site combustion of refuse from both single dwellings (homes) and multiple dwellings (apartments). Hotels are considered to be commercial buildings rather than dwellings.

Refuse from single or multiple dwelling units is very similar in composition and heat content to municipal refuse. The source is the same; only the location of the point for volume reduction is changed. Therefore, lacking specific data, one should use 4,450 BTU/lb. for domestic refuse.

Apartment or multiple dwelling incinerators are usually one of the following types: (a) flue-fed units, (b) "controlled (starved) air" type units with forced draft fans for combustion air control, or (c) multiple chamber units. In flue-fed incinerators, refuse is charged directly into the exhaust flue, the bottom of which opens into the top of the furnace. Much work has been done to reduce the air pollution problems of flue-fed incinerators by means of draft controls and/or afterburners, but many uncontrolled units remain in use. A newer type of domestic incinerator is the "controlled" air furnace which has forced draft fans and dampers for draft control.[10]

Private home incinerators have decreased greatly over the past decade due to voluntary use of municipal disposal systems or restrictions on small incinerators by local ordinances.[1] Three basic types of home incinerators have been used: (a) the dehydrating types, (b) high BTU input units, and (c) after-burner types. The first two types are no longer recommended, but some units may remain in use. The after-burner units can be quite effective and are sometimes the only home units not prohibited by local laws.[9]

"Flue-Fed Incinerators"

GAS FLOW RATE

Exhaust flow data for flue-fed incinerators are given in Table III-3.1. The actual gas flow rates (acfm) vary widely because of the lack of draft control but typically are between 850 - 2,500 acfm with an average of about 1,600 acfm.[7]

Exhaust flow data for flue-fed incinerators modified with a draft control damper and roof afterburner also are given in Table III-3.1

and plotted in Figure III-3.1. The average stack flow per unit of refuse burned is 10 scfm per lb./hr. of refuse burned with a range of 7.6 - 12.0 scfm per lb/hr. refuse. These same values in acfm at 1268°F are 34 and 25.2 - 39.8 respectively.

GAS TEMPERATURE

Exhaust gas temperatures for uncontrolled units are not well documented, but based on stack flow rates and firing rates they should average about 700°F. Temperature data for modified installations with afterburners average about 1200°F,(Table III-3.1).

GAS VELOCITY

Gas velocities of uncontrolled flue-fed incinerators show extreme variations because of the lack of draft control. Velocities ranging from 8.0 - 24.0 fps were observed for one unit.[7] The average velocity was about 16 fps.

Stacks for flue-fed incinerators are generally 16" x 16" in cross-section (flue liners are commonly sold in 12", 16" and 24" sizes). Using the 16" dimensions and the flow rates from Table III-3.1 velocities for modified units can be calculated. These calculations yield an average velocity of 21 fps. Therefore, where specific data are unavailable, 20 fps may be assumed.

STACK HEIGHT

Stacks for flue-fed incinerators are generally only a few feet higher than the apartment house they serve. Garden apartments would normally be about 3 stories whereas high-rise apartments would be 10 or more. A typical range in stack height would be 25-80 feet (Table III-3.1). When specific data is not available, assume 35 feet.

"Controlled-Air Incinerators"

GAS FLOW RATE

Using a standard refuse with an "as fired" heating value of 6,030 BTU/lb. and operating data from Table III-3.2, a plot of stack gas flow rate (scfm/(1,000 BTU/hr.))versus percent excess air was made (Figure III-3.2). The actual gas flow rate (acfm) at several representative temperatures is shown in Figure III-3.3.[10]

GAS TEMPERATURE

The average temperature of stack gases from the 6 tested incinerators was 983°F with a range of 464 - 1650°F. Common temperatures were in the range of 800 - 1100°F. When specific information is not available 1000°F should be assumed.

GAS VELOCITY

The average velocity of the exhaust gases for the "controlled" air units was 30.5 fps with a range of 16.9 - 41.1 fps. Where specific data is unavailable, 30 fps should be assumed.

STACK HEIGHT

The stack height of the 6 tested units ranged from 20-33 feet; 25 feet should be assumed.

"Home-Incinerators"

GAS FLOW RATE

Test data for home incinerators including each of the three model types described earlier are presented (Table III-3.3 and III-3.4)[9]. These data were used with Figure III-3.1 to estimate the average stack gas flow during burning of a full charge of garbage or rubbish in home incinerators (Table III-3.5). The gas flow rates are summarized below:

Incineration Type	Exhaust Flow Rate scfm	acfm	Temperature
Dehydrating	3-4	7-9	618 - 845°F
High Input	33-51	89-137	877 - 883°F
After Burner	31-41	82-109	805 - 914°F

Since only the afterburner type is still recommended for use in homes, most emphasis should be placed on this data for that. When specific data are unavailable use 35 scfm.

GAS TEMPERATURE

The only temperatures available for home units were peak flue gas temperatures which ranged from 250 - 1,180°F (Table III-3.4). These temperatures are not reached immediately and they are transient even when reached. There is generally little cooling of the gases between the furnace and outlet. The average temperature for home incinerator exhaust should be assumed to be about 500°F.

GAS VELOCITY

By assuming the stack to be a 6 in. round duct, as it usually is, the gas volume flow rates discussed previously can be used to calculate typical stack gas exit velocities. The values are as follows: (a) dehydrating units: 0.6 - 0.8 fps, (b) high input units: 7.6 - 11.6 fps, (c) after-burner units: 7.0 - 9.3 fps. Where specific data are unavailable, 9 fps should be used.

STACK HEIGHT

The stack from a home incinerator will discharge about 3 feet above the roof line which ranges from 10 - 20 feet. Where specific data are unavailable, 15 feet should be used.

TABLE III-3.1

Exhaust Gases from Flue-Fed Incinerators[7]

	Firing Rate (lb./hr.)	Exhaust Flow (scfm)	scfm per lb. refuse/hr.	Stack height (ft.)	Outlet Temp. °F
	Uncontrolled				
	63	458	7.3	25	
	162	1190	7.3	35	
	24.4	326	13.4	68	
	76.0	820	10.8	80	
	98.5	930	9.5	80	
	61.7	500	8.1	54	
	83.5	1120	13.4	56	
	128	860	6.7	80	
	124	530	4.3	25	
	128	441	3.4	56	
	160	817	5.1	46	
Avg.	101	725	8.1	55	
Range	24.4-162	326-1190	3.4-13.4	25-80	
	Modified with draft control damper and roof afterburner.				
	100	760			1130
	80	690			1240
	68	710			1130
	49	590			1560
Avg.	74.3	688			1265
Range	49-100	590-760			1130-1560

Exhaust Gases From "Controlled Air" Incinerators

Model and Test No.	Refuse Burning Rate (lb./hr.)	Fuel Input (1000 BTU/hr.)	Average Flow (scfm)	Exhaust Rates (acfm)	Excess Air (%)	Avg. Stack Gas Velocities (fps)	Avg. Stack Gas Temp. ^oF	Stack Height (ft)
A.1	625	858	1340	5100	136	37.9	1519	33
A.2	625	850	1340	5440	131	39.2	1650	33
B.1	330	342	1070	2830	359	32.5	916	21.5
B.2	330	356	1080	2770	397	31.2	874	21.5
B.3	330	338	1030	2770	376	31.6	940	21.5
C.1	800	0	471	1360	50	35.4	1037	22
C.2	800	0	458	1290	48	33.8	1002	22
D.1	300	321	1062	2530	410	24.2	780	21
D.2	300	346	1162	3010	360	28.6	888	21
E.1	320	171	516	1740	72	41.1	1296	20
E.2	320	190	571	1140	170	18.0	580	20
E.3	320	173	587	1770	105	28.8	1108	20
E.4	320	197	612	1190	217	16.9	464	20
F.1	160	97.5	342	860	60	26.7	850	20
F.2	160	98.5	374	942	62	30.1	850	20

TABLE III-3.3

Exhaust Gases From Home Incinerators Burning Garbage[9]

Model	Type[a]	Capacity (ft^3)	Total BTU/hr. Input	BTU Input per lb. refuse consumed	Excess Air (%)	Peak Flue Gas Temperature $(^{\circ}F)$
A	D	1.86	2,000	---	--	--
B	D	1.86	2,000	14,250	670	835
C	D	1.61	1,100	10,600	650	510
D	D	2.23	1,500	8,700	549	505
E	H	2.23	20,000	7,300	319	1280
F	H	1.86	10,000	---	413	380
G	H	1.86	20,000	---	488	470
H	H	1.86	20,000	5,580	365	735
J	H	2.11	10,000	3,800	453	710
K	H	1.86	12,000	---	312	1270
L	H	1.86	10,000	1,850	590	1330
M	H	1.86	20,000	3,720	593	920
N	H	1.86	20,000	3,750	440	800
O	A	1.98	38,000	14,500	302	620
P	A	1.86	30,000	11,200	472	660
Q	A	1.86	30,000	11,300	339	670
R	A	2.48	35,000	19,800	420	620
S	A	1.86	35,000	13,200	340	985
T	A	1.86	35,000	14,250	348	860
U	A	1.86	38,000	17,100	182	980
V	A	1.98	35,000	22,700	289	650
W	A	1.86	35,000	13,900	190	1160
X	A	1.86	38,000	12,500	203	840

a. D--dehydrating, H--high input, A--after burner.

Table III-3.4

Exhaust Gases From Home Incinerators Burning Rubbish[9]

Model	Type[a]	Capacity (ft^3)	Total BTU/hr. Input	BTU Input per lb. refuse consumed	Excess Air (%)	Peak Flue Gas Temperature (°F)
A	D	1.86	2,000	---	---	---
B	D	1.86	2,000	51,500	409	1100
D	D	2.23	1,500	31,400	555	590
E	H	2.23	20,000	26,400	---	---
F	H	1.86	10,000	---	---	---
G	H	1.86	20,000	---	480	600
H	H	1.86	20,000	20,200	342	550
J	H	2.11	10,000	13,700	380	---
K	H	1.86	12,000	---	290	1020
L	H	1.86	10,000	6,700	297	1230
M	H	1.86	20,000	13,400	217	1140
N	H	1.86	20,000	13,600	310	760
O	A	1.98	38,000	52,400	213	700
P	A	1.86	30,000	40,500	430	700
Q	A	1.86	30,000	40,800	254	920
R	A	2.48	35,000	71,500	321	720
S	A	1.86	35,000	47,600	233	1020
T	A	1.86	35,000	31,500	349	800
U	A	1.86	38,000	61,800	126	250
V	A	1.98	35,000	82,000	320	680
W	A	1.86	35,000	50,200	153	1180
X	A	1.86	38,000	45,100	95	1180

a. D--dehydrating, H--high input, A--after burner.

Table III-3.5

Calculated data for home incinerators

(Based on Tables III-3.3 and III-3.4)

Type[a]	Charge Type	Charge (lb)	Excess Air (%)	Exhaust[b] Flow (scfm)	Flue Gas[c] Temperature °F
D	Garbage	61.5	623	4	618
D	Rubbish	17.0	482	3	845
H	Garbage	62.6	441	51	877
H	Rubbish	17.4	331	33	883
A	Garbage	63.2	309	41	805
A	Rubbish	17.5	249	31	914

a. D--dehydrating, H--high input, A--after burner.
b. Estimated value during burning of charge.
c. Peak temperatures.

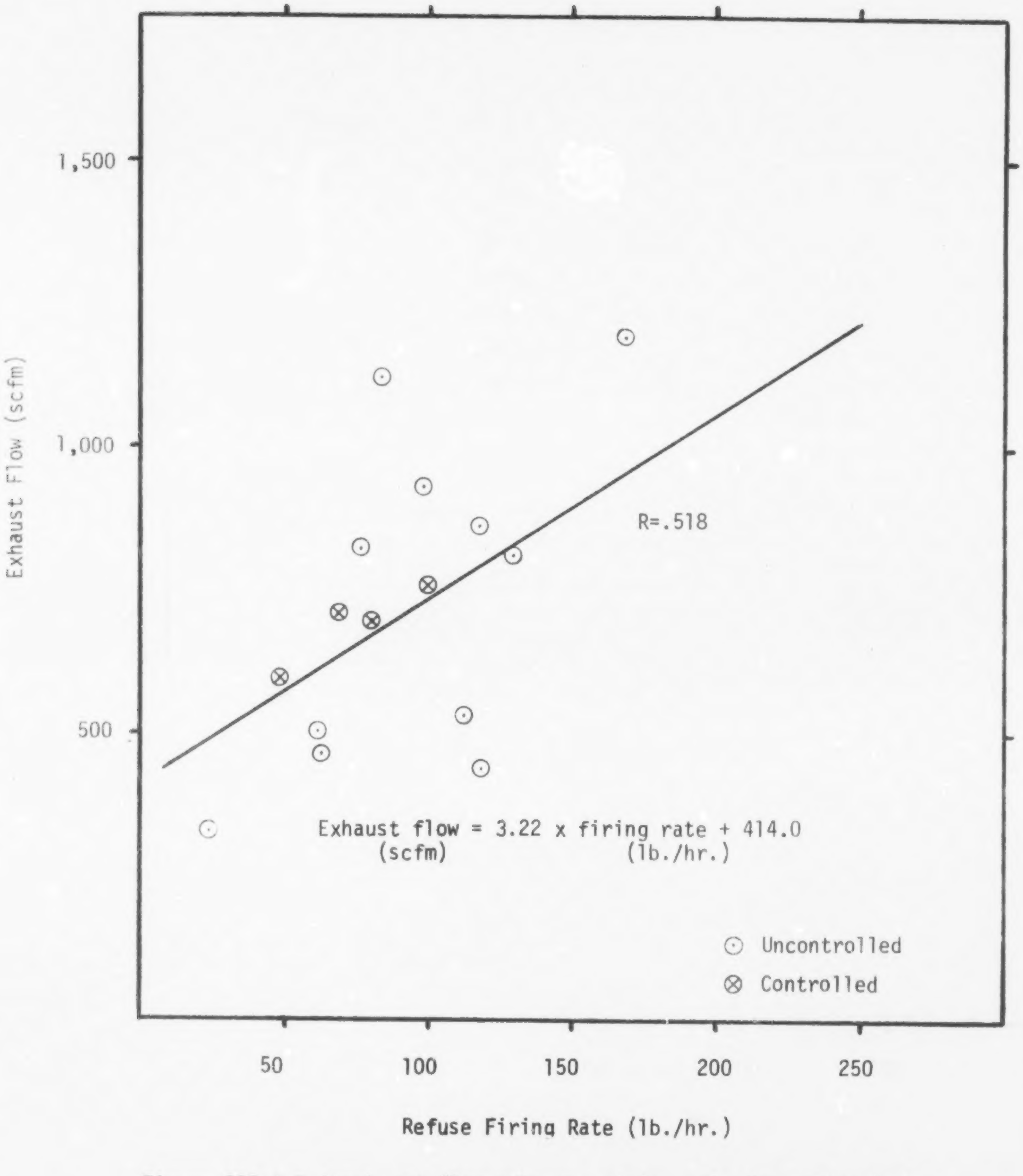

Figure III-3.1 Stack gas flow rate vs. firing rate for controlled and uncontrolled flue fed incinerators[7]

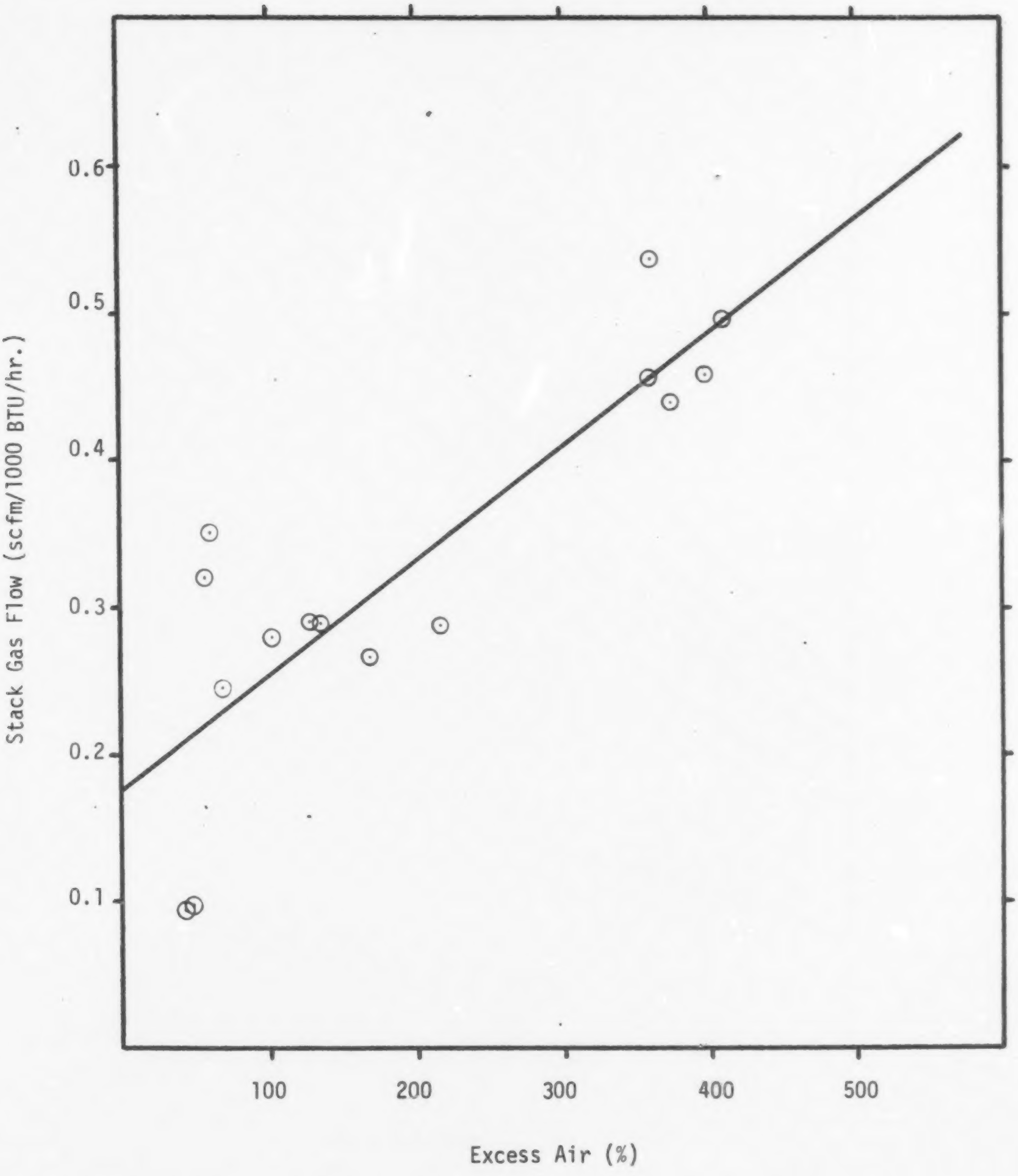

Figure III-3.2 Stack gas flow for "controlled air" domestic incinerators

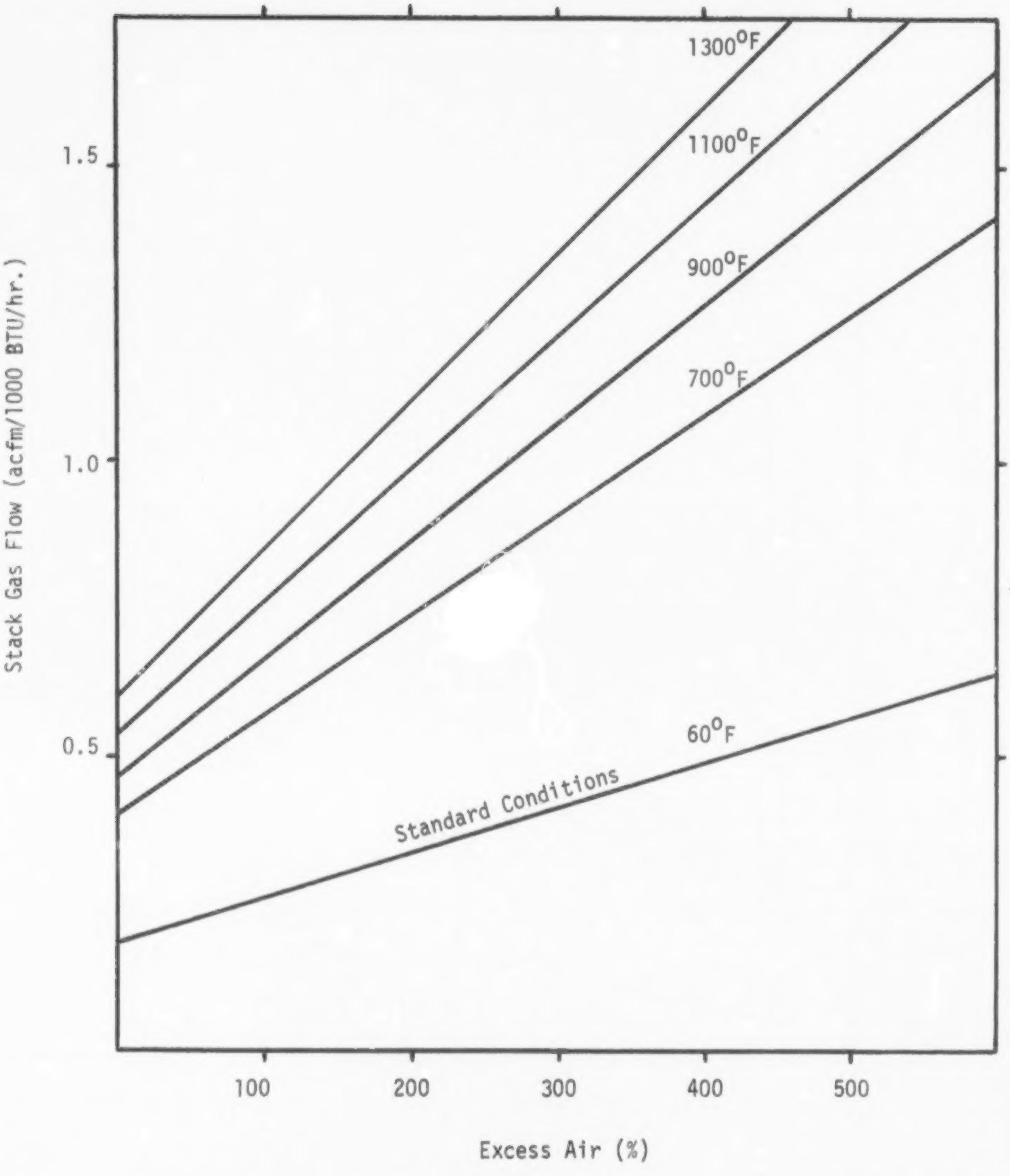

Figure III-3.3 Stack gas flow for "controlled air" domestic incinerators at typical exhaust temperatures

CHAPTER III-4

PATHOLOGICAL INCINERATION[B]

Pathological waste is defined to include all, or parts of, organs, bones, muscles, other tissues and organic wastes of human or animal origin.[7] These wastes have a very low heating value, typically about 1000 BUT/lb. To ensure complete destruction of these wastes very high fuel firing rates are recommended, about 8000 BTU/lb. of waste (5000 BTU in the primary chamber and 3000 BTU in the secondary chamber).[5] Because of the hazards involved in storing and handling pathological wastes, recommended design standards are likely to be followed for operation of these incinerators. They are generally operated once or twice per day for 1.5-2.5 hours.[1,7]

GAS FLOW RATE

Excess air requirements for pathological incineration are generally about 100 percent for the waste itself and 20 percent for the natural gas fuel for the burners. If natural gas consumption is set at 10 scf/lb. of waste, the exhaust volume will be about 5.0 scfm per lb. of waste/hr.[7] Figure III-4.1 shows calculated stack gas flow as a function of disposal rate both at standard temperature and at several typical temperatures.

GAS TEMPERATURE

High gas temperatures are essential for incineration of pathological wastes. The secondary chamber of the incinerators is normally operated at 1600°F, and stack gas temperatures are usually in the range of 800 to 1200°F.[2,5,7] These high temperatures result in relatively clean exhaust gases in most conditions, and water scrubbers have rarely been used in the past. In such instances, a gas temperature of 1000°F should be used where specific data are unavailable.

GAS VELOCITY

Pathological incinerator stacks are frequently sized to give exit velocities of 20 fps at design firing rates and an exhaust temperature of 1400°F.[2,5,7] With the usual stack temperatures, velocities should be in the range of 13.5 - 15.7 fps. Assume 15 fps when data are unavailable.

STACK HEIGHT

Since pathological incinerators will often be associated with commercial buildings or hospitals, stack heights will range from 25 feet upward to 80 or more. Assume 50 feet when specific data are unavailable.

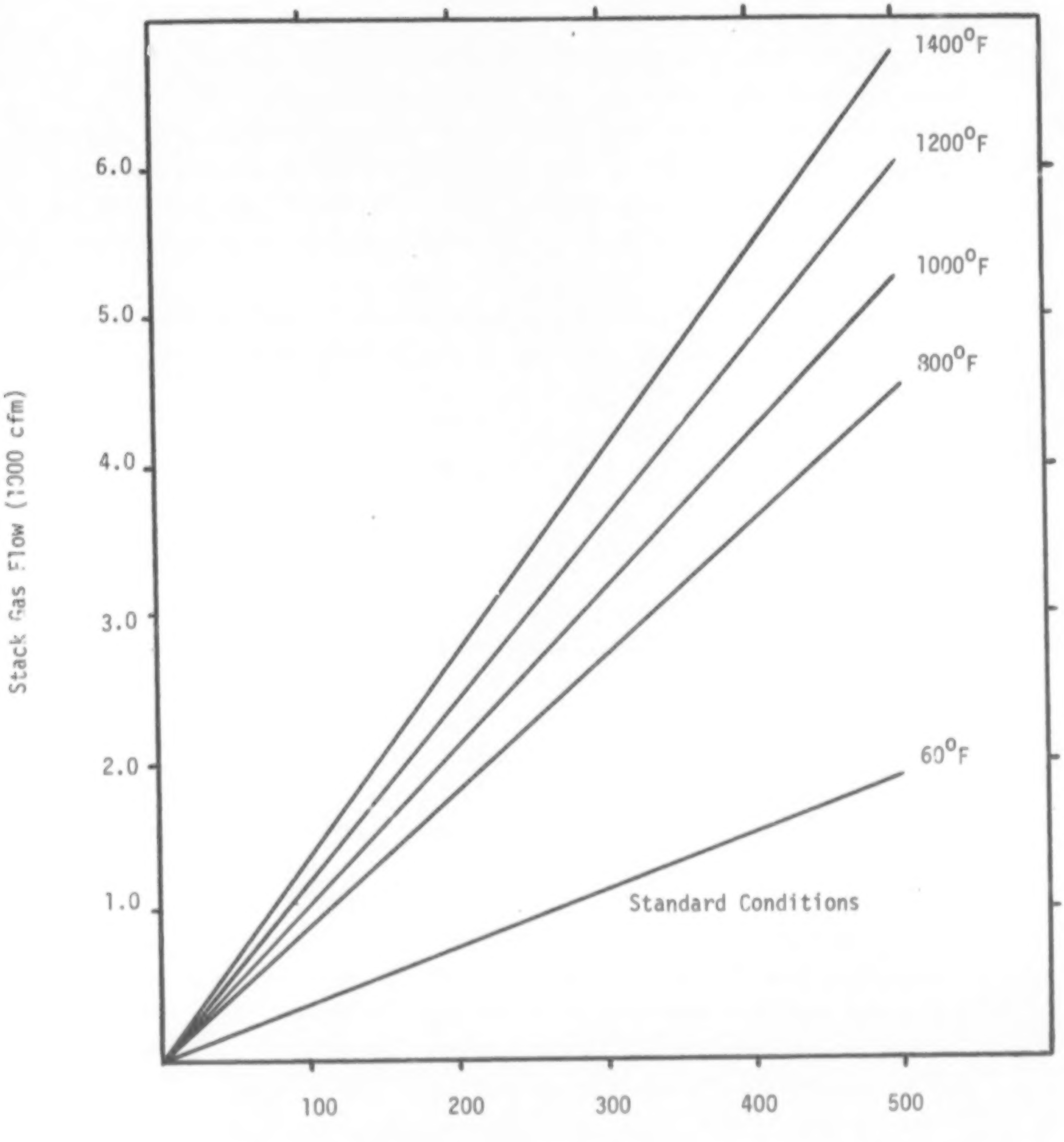

Figure III-4.1 Stack gas flow for pathological incinerators

CHAPTER III-5

AUTO BODY INCINERATION [B]

The auto body incinerator has two main parts: (a) a primary furnace which surrounds the automobile body and prevents excessive heat loss by convection and radiation, and (b) a secondary chamber in which auxiliary fuel, typically No. 4 fuel oil, is burned to complete combustion of any residue present in the gases from the primary chamber.[11] The units may be either continuous in operation or batch processes, but the principles of operation are similar.

Because auto incinerators are usually privately owned and represent a considerable capital expenditure, they would likely operate 8 hours per day for 5 or 6 days a week.

GAS FLOW RATE

Test results for a 2-car batch unit with a 5 million BTU/hr. oil burner indicate that about 166,400 scf of flue gas is produced in an average burn lasting 38 min.[11] This results in an average stack flow of 4,380 scfm during the burn. Because most of the flue gas results from the oil burner operation, this figure would probably not change much when only one car body is burned. For a continuous operation with better overall control of the process, the stack flow would probably be 2000 - 3000 scfm.

The actual gas flow rate of the tested unit was 12,900 acfm at an estimated exhaust temperature of 1075°F. In a continuous unit, flow rates in the range 6000 - 9000 acfm might be expected at the same temperature.

GAS TEMPERATURE

The average stack temperature of a batch unit was 1075°F. The expected temperature range during a burn is 800 - 1800°F. Because the temperature required for smokeless operation of a continuous process is the same as for a batch process, the average exhaust temperatures would not be expected to differ much, and 1100°F should be assumed.

GAS VELOCITY

With a stack of 47-inch i.d. (internal diameter), the gas velocity would be 25 fps. With the more usual 39-inch i.d. stack, the velocity would be about 36 fps. Where specific data are not available 30 fps should be assumed.

STACK HEIGHT

The manufacturer's suggested stack height is 55-60 feet to create adequate draft for the incinerator. Where no data are available 50 feet should be assumed.

CHAPTER III-6

CONICAL BURNERS [B]

The conical burner (tepee burner) has traditionally been used for the disposal of wood waste, cotton gin waste, peanut hulls and other agricultural waste. In addition, some smaller cities (100,000 population) use them for municipal refuse disposal. Typical rated capacities range from 5,000 to 10,000 lb./hr. They generally operate 10 hours per day, 6 days per week.[12]

GAS FLOW RATE

Tepee burners with adequate underfire air systems should be operated at excess air levels of 300 - 500 percent which is less than natural draft units use.[13] In very poorly controlled conical burners, excess air levels could approach those for open burning which may be 5000 percent or more.[14] When data are unavailable, assume 1000 percent excess air.

Figure III-6.1 shows the exhaust gas volumes expected from disposal of municipal waste in tepee burners utilizing 1000 percent excess air. The refuse is assumed to have a heating value of 4,450 BTU/lb. as fired.

GAS TEMPERATURE

In a properly operated conical burner temperatures near the exhaust dome should be 750 - 900°F.[13] However, a survey of tepee burner installations found that less than ½ of the burners even had usable doors; this results in essentially no control over excess air, and as a result, no control over temperatures.[12] An approximate heat balance using data from reference 13 and assuming 5000 percent excess air indicates that, in the worst case (open burning) temperatures could fall as low as 140°F. When data are not available, 400°F may be used as an approximate temperature. (Figure III-6.2)

GAS VELOCITY

The usual tepee has a 15 to 20 foot diameter dome (stack opening), equipped with 2½ mesh steel wire for collection of large fly ash particles. Exhaust velocities for a tepee burner burning municipal waste with a 17.5 foot diameter exhaust dome, an exhaust temperature of 825°F, and 400 percent excess air, would be between 5 and 25 fps. When no data are available, 15 fps should be assumed.

STACK HEIGHT

Tepees vary from 10 feet in diameter by 12 feet high to 90 feet in diameter by 97 feet high. One survey found the typical size for tepees to be 52 feet in diameter by 57 feet high.[12] Where specific data are unavailable, 60 feet should be assumed for stack height.

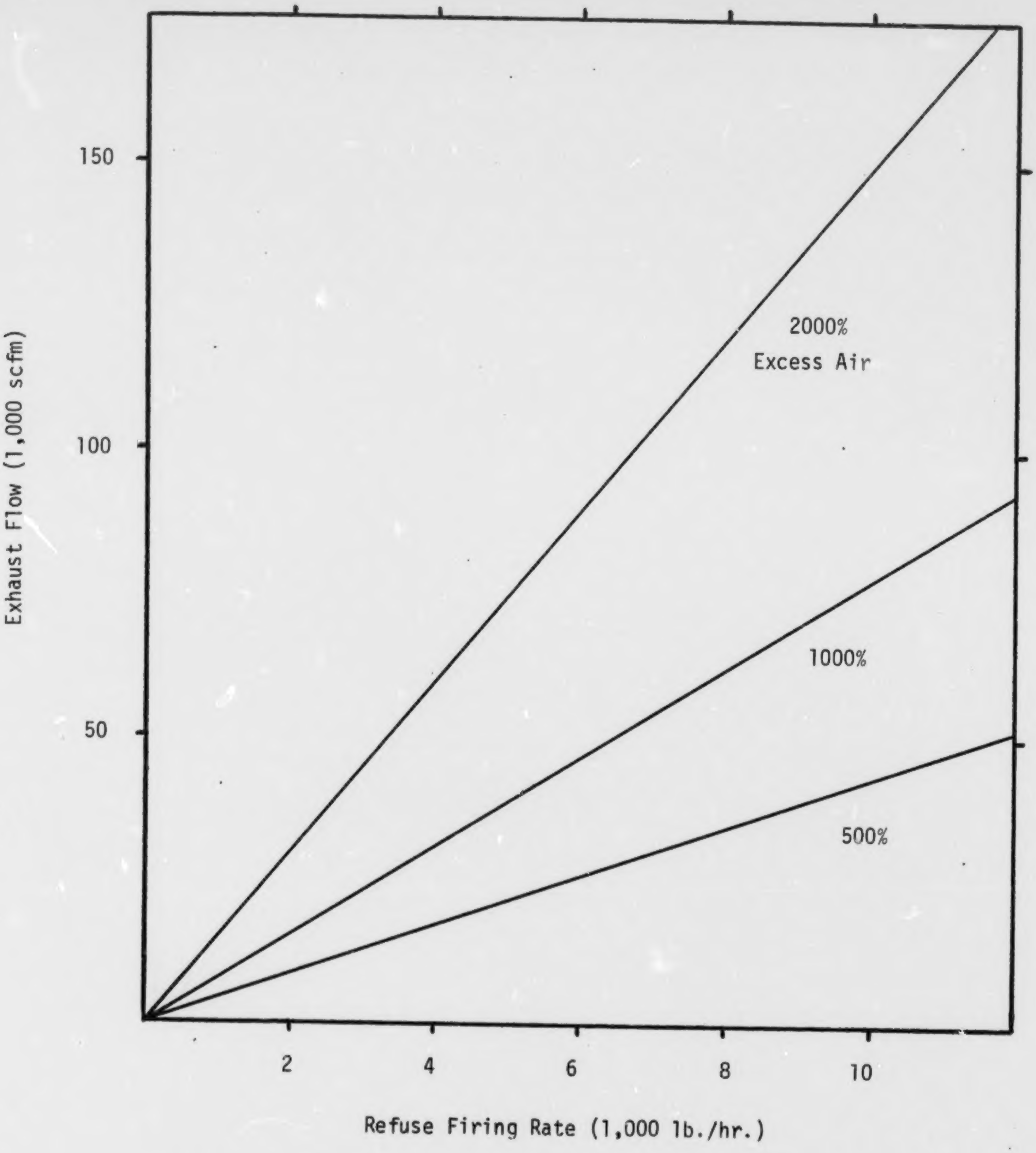

Figure III-6.1 Exhaust flow rates from conical burners

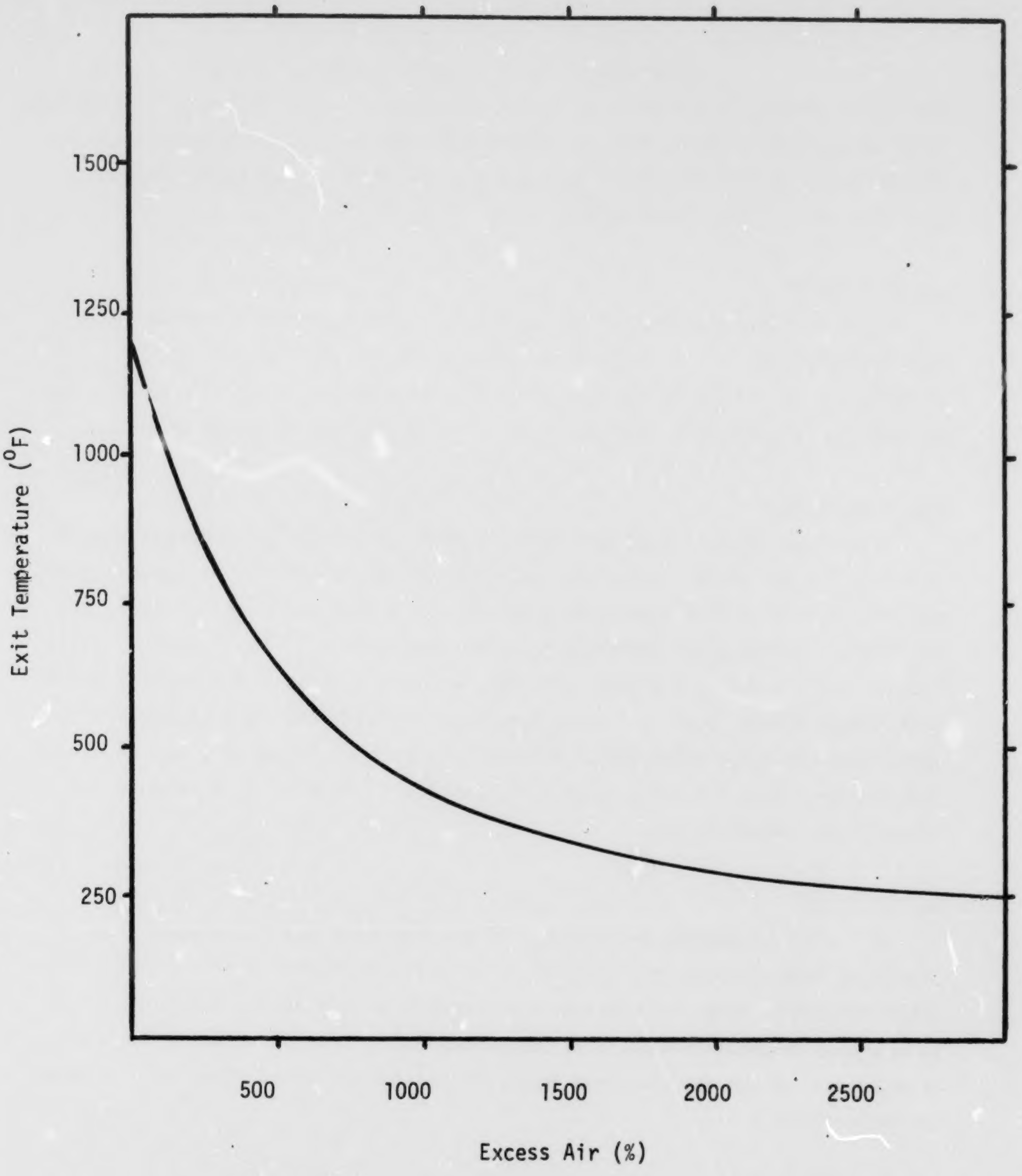

Figure III-6.2 Correlation between temperature and excess air

CHAPTER III-7

OPEN BURNING[c]

Virtually any combustible refuse may be disposed of by open burning, but three common types of this refuse are (a) municipal refuse, (b) landscape (yard or garden) refuse, and (c) combustible automobile components such as tires, seats and floor mats. Open burning in dumps normally occurs for about 8 hours, 6 days per week.

GAS FLOW RATE

A very rough estimate of the entrained air volume in the smoke plume from open burning can be made from emission data. This was done for three types of refuse (Table III-7.1).[14] Gas flow at various burning rates is depicted graphically in Figure III-7.1 for the three types of refuse.

GAS TEMPERATURE

Gas temperatures from open burning show considerable variation both with the height above the refuse and with ambient temperature. In addition, the temperature varies throughout the course of the burn. In general, the temperature rises after ignition to a maximum within 2 to 5 minutes, falls rapidly for 10 to 15 minutes, and then drops very slowly for several hours. Peak temperatures, the time after ignition at which the peak occurs, and the approximate average temperature over the first hour of burning are tabulated (Table III-7.2). For dispersion calculations 150°F should be assumed for exhaust gas temperatures.

GAS VELOCITY

An order of magnitude estimate of gas velocity was calculated from simulated open-burning experiments on an 8-ft. diameter table. In the tests the smoke plume maintained one diameter to the 24-ft. level.[14] By assuming temperature and air entrainment of a free plume to be the same as measured in the experimental work, we calculated velocities, of the data in Table III-7.2.

Refuse Type	Gas Velocity
Municipal	0.7 fps
Landscape	0.6 fps
Automobile	1.0 fps

A velocity of 50 fpm is about the lowest velocity that can be felt in comfort air conditioning; the exit velocity of combustion gases from burning refuse has to be somewhat higher. For calculations, assume 2 fps.

STACK HEIGHT

For dispersion calculations, use area formulas for a ground level source.

TABLE III-7.1

Exhaust Gases From Open Burning[14]

Refuse Type	Excess Air (%)[a]	scfm per lb./hr.	Avg. Temp.[b]	acfm per lb./hr.
Municipal	5100	20	150°F (66°C)	23
Landscape	6500	17	150°F (66°C)	20
Automobile	4900	25	200°F (93°C)	32

a. In the true sense, this is dilution (or entrained) air.
b. Measured 24-ft. above the burning refuse in a duct connected to a large inverted cone above the burning rope.

TABLE III-7.2

Peak Gas Temperatures for Open Burning

Refuse Type	Time of Peak (min)	Peak Temperature °F	Approx. Avg. Temperature °F
Municipal	2	375	150
Landscape	3	230	150
Automobile	4	485	200

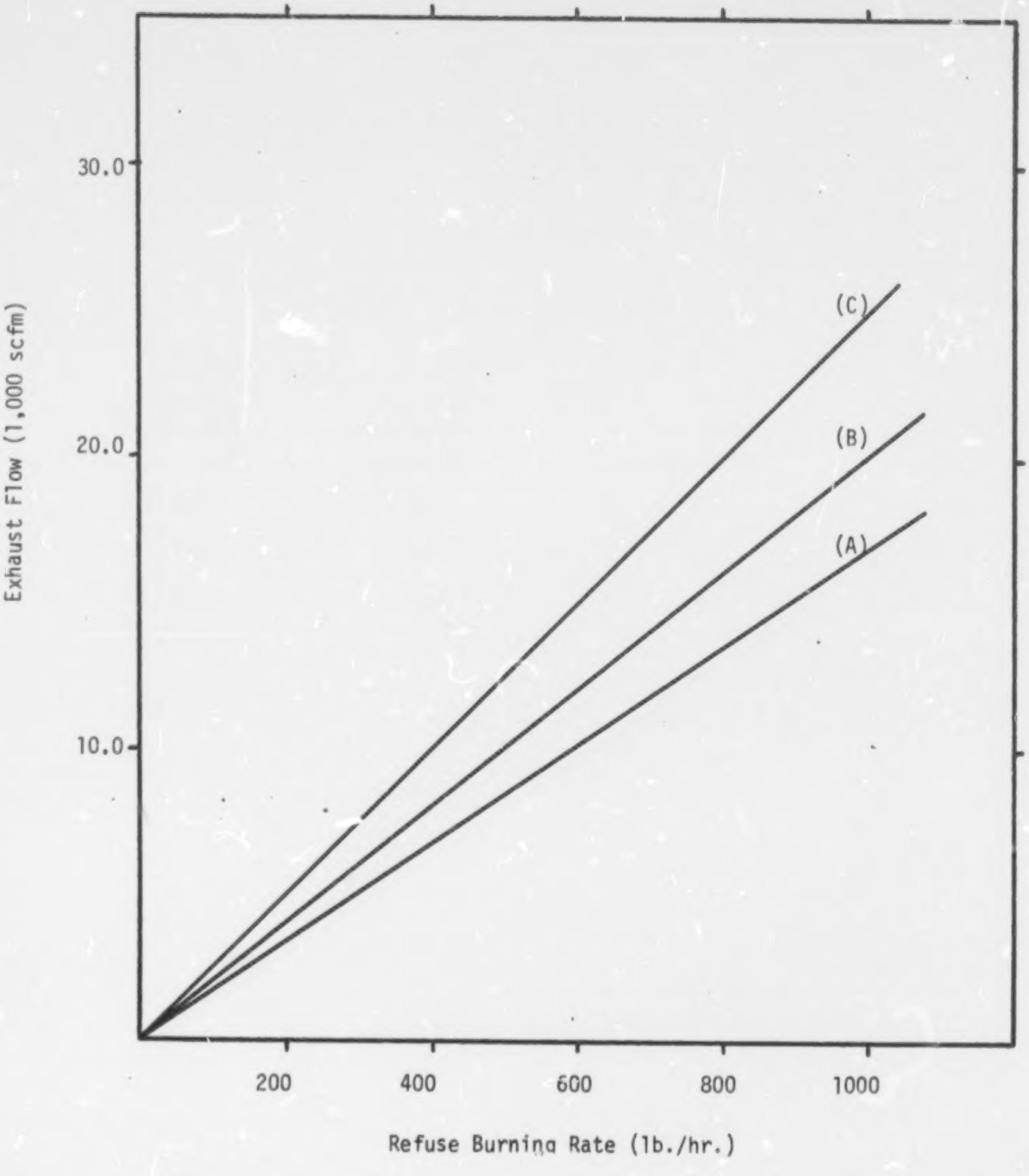

Figure III-7.1 Exhaust flow from open burning of: A. landscape refuse, B. municipal refuse, and C. automobile components

CHAPTER III REFERENCES

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CHAPTER IV-1

AMMONIA PLANT [C]

Ammonia (NH_3) is an interim chemical product used chiefly in the manufacture of fertilizer. There are about 100 plants in the U. S. which have a total annual production rate of 20 million short tons. Demand for ammonia has been increasing for several decades and is expected to continue. Since 90 percent of the ammonia manufactured in the U. S. uses natural gas as feedstock, many plants are located near gas fields in the Louisiana and Texas area. Typical plant capacities are 400 to 600 tons per day with newer plants having capacities as high as 1500 tons per day. Ammonia plants operate continously.

Commercial production of ammonia is accomplished by reacting hydrogen and nitrogen at high temperatures and pressures over a catalyst. In the typical plant (Figure IV-1.1), the hydrocarbon (usually natural gas) is mixed with steam in the reformer to yield carbon monoxide and hydrogen. These gases are then scrubbed to remove the carbon monoxide and carbon dioxide impurities. The process gases, which now consist mainly of nitrogen and hydrogen, are compressed and fed to the converter where the gases react to form ammonia. Each plant will operate at different pressures and temperatures depending on feedstock quality, type of equipment being used and the specific process. Reference 1 lists 11 different processes with typical operating pressures, temperatures and percent conversion. Figure IV-1.2 shows the consumption of natural gas as feedstock and as fuel as a function of plant capacity.[2]

GAS FLOW RATE

To attain the required high temperatures, some natural gas is burned to supply direct heat to the primary gas reformer. Exhaust from the combustion of this fuel represents the major volume flow emission point. Control equipment is not normally used. Equation IV-1.1 can be used to calculate the flow rate from this source, assuming 25% excess air, 1050 BTU/scf of natural gas and .0750 lb/scf air.

Exhaust flow rate (scfm) = Natural gas use (1000 scfh) x 222. IV-1.1

GAS TEMPERATURE

Exhaust temperature from fuel combustion ranges from 700 to 1100°F with an average of 950°F.

GAS VELOCITY

No data were available. Assume 50 fps if the velocity cannot be calculated from specific source data.

STACK HEIGHT

The stack used to exhaust this source is usually less than 2½ feet in diameter and is about 75 to 100 feet high. Other emission points within the perimeter of the plant include flash gas vents, bleed off vents, and storage vents.

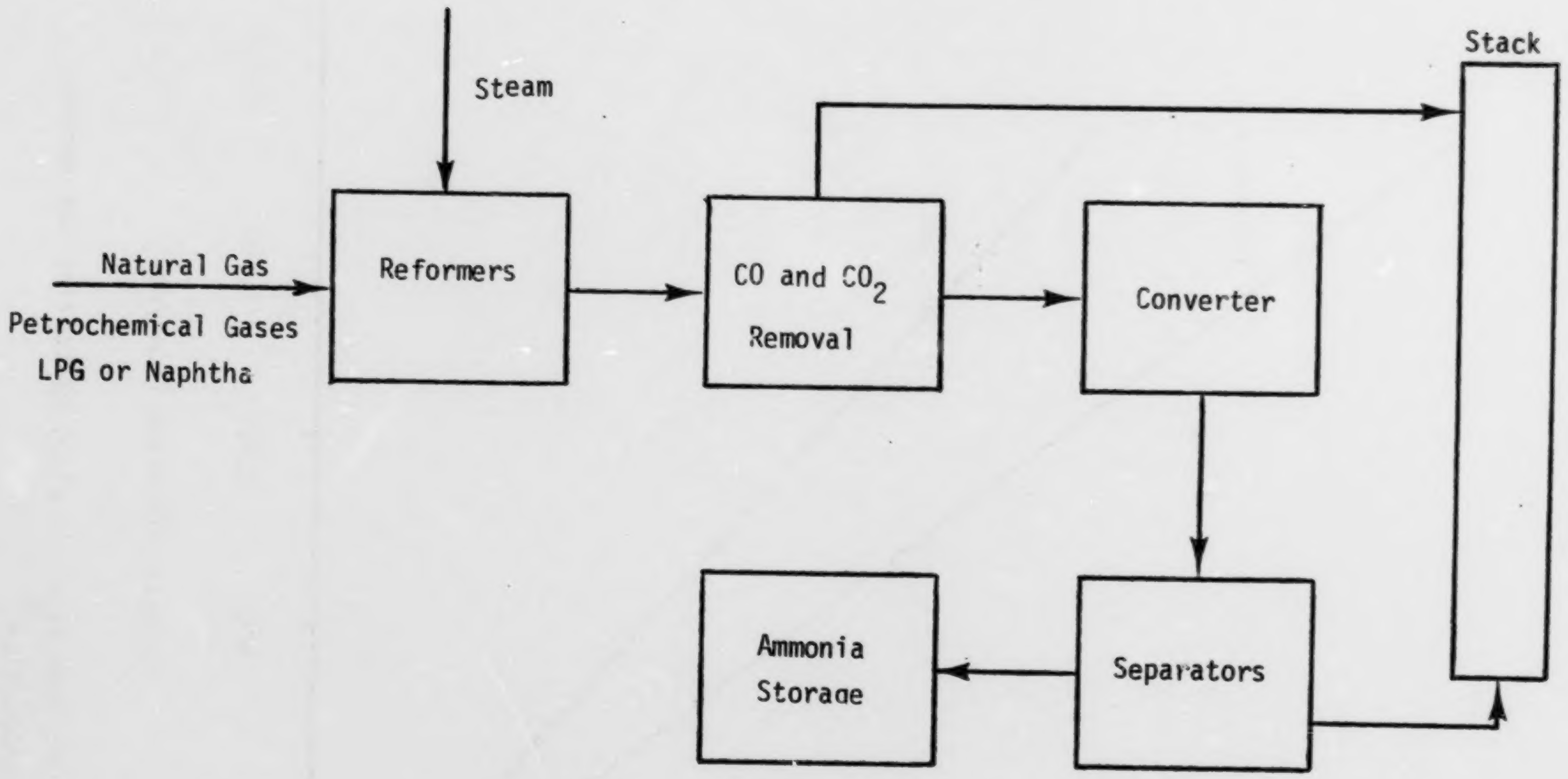

Steam
Stack
Natural Gas
Petrochemical Gases
LPG or Naphtha
Reformers
CO and CO_2
Removal
Converter
Ammonia
Storage
Separators

Figure IV-1.1 Process flow diagram of a synthetic ammonia plant

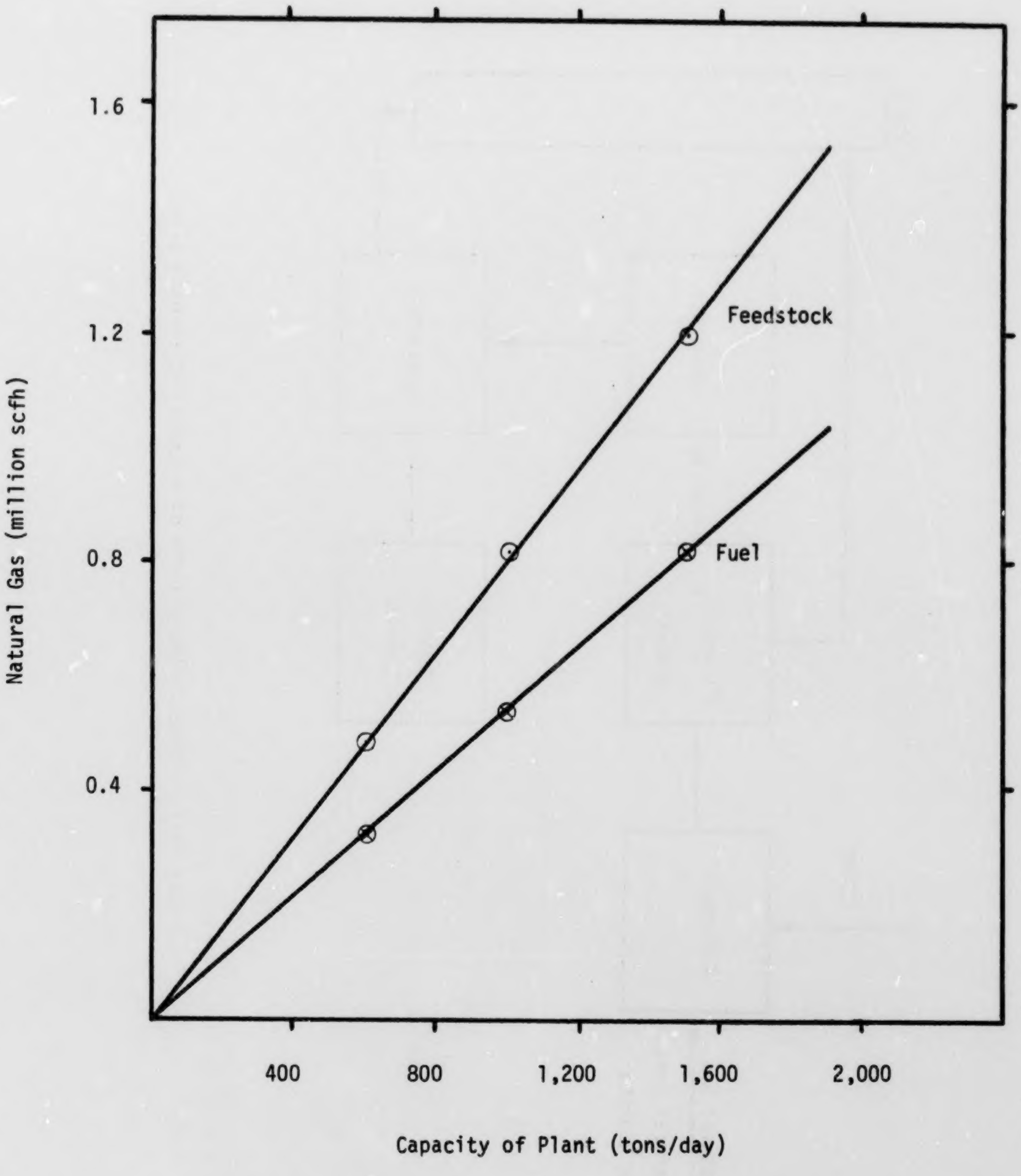


Figure IV-1.2 Gas feed rate vs. plant capacities for ammonia production[2]

CHAPTER IV-2

CARBON BLACK PLANT [c]

Carbon black is an ultrafine soot manufactured by the burning of hydrocarbon fuels in a limited supply of air. The finely divided material (10 to 400 microns in diameter) is of industrial importance as a reinforcing agent for rubber (94 percent) and as a colorant for printing ink, paint, paper, and plastics (6 percent). The 1969 annual production rate was 2.96 billion pounds.

Carbon black is produced by burning oil and/or natural gas with a limited supply of air at temperatures of 2500 to 3000°F. Part of the fuel is burned to CO_2, CO and water vapor thus generating heat for the combustion of fresh feed. The unburned carbon is collected as black fluffy particles. There are three basic processes for producing this compound: the furnace process which uses gas and/or oil, accounting for about 83 percent of the U.S. production, the older channel process which accounts for about 6 percent of the production and the newer thermal process which produces the remaining 11 percent.[3]

The furnace process, using natural gas both as the source of heat and feed, is commonly employed for making the finer grades of carbon black. About 40 percent of the natural gas is used for heat and sixty percent is converted to carbon black. The amount of feed necessary to make carbon black, however, will vary with the size of particle produced (Figure IV-2.1).[4] Common yields (carbon collected as carbon black/carbon in the fuel) are 25 to 30 percent for the larger particle size and 10 to 15 percent for the smaller particle size black.

The most popular method of making carbon black is the oil furnace process which uses oil as the raw material. The feed stock is a specially refined oil which contains about 90 percent carbon. Yields from the oil furnace are greater than those of gas process and range from 35 to 65 percent depending on the grade of black produced. Figure IV-2.2 shows the yields for the oil furnace process.[5] Oil furnace grades of carbon black are identified as follows:

SRF	Semireinforcing furnace
HMF	High-modulus furnace
GPF	General-purpose furnace
FEF	Fast-extrusion furnace
HAF	High-abrasion furnace
SAF	Superabrasion furnace
ISAF	Intermediate-abrasion furnace

The yield of carbon black process also depends on efficiency of the carbon black collection system. It is common to find several types of air pollution control devices used in series to collect the carbon particles like cyclones and electrostatic precipitators.

GAS FLOW RATE

For all practical purposes the exhaust flow rate is 5 scf of exhaust gas for 7 scf of natural gas used in the furnace process. The different grades of carbon black are produced by varying the air fuel mixture and using different types of gas (having different methane analysis). More air will result in finer particles.

In order to get SAF grade of carbon black, 50 percent of stoichiometric air is required. To get HAF 80 percent of stoichiometric air is used (Figure IV-2.3)[5].

In the channel process natural gas is burned with a limited air supply in long low buildings. The flame contacts long steel channel sections depositing the soot (carbon black) which is scrapped off later. The yields of this process are low, 1 to 1.5 pounds of carbon black per 1000 ft.^{3} of natural gas. Exhaust air flow is 100 scfm/1000 cfh of natural gas.

GAS TEMPERATURE

Stack gas temperature ranges from 400 to 1000°F depending mainly on the finished product; for modeling assume 500°F.

GAS VELOCITY

Gas velocity from the furnace black plants was not available. Based on natural gas or oil combustion operations, velocities of 30 - 60 fps might be expected. Observations of emissions from channel black plants suggest exit velocities on the order of 10 fps.

STACK HEIGHT

Stack heights for the furnace black plants are expected to be consistently in the range of 150 to 200 feet. Channel black plants have no specific stacks, so emissions would be generated as a line or area source at heights of no more than 20 feet.

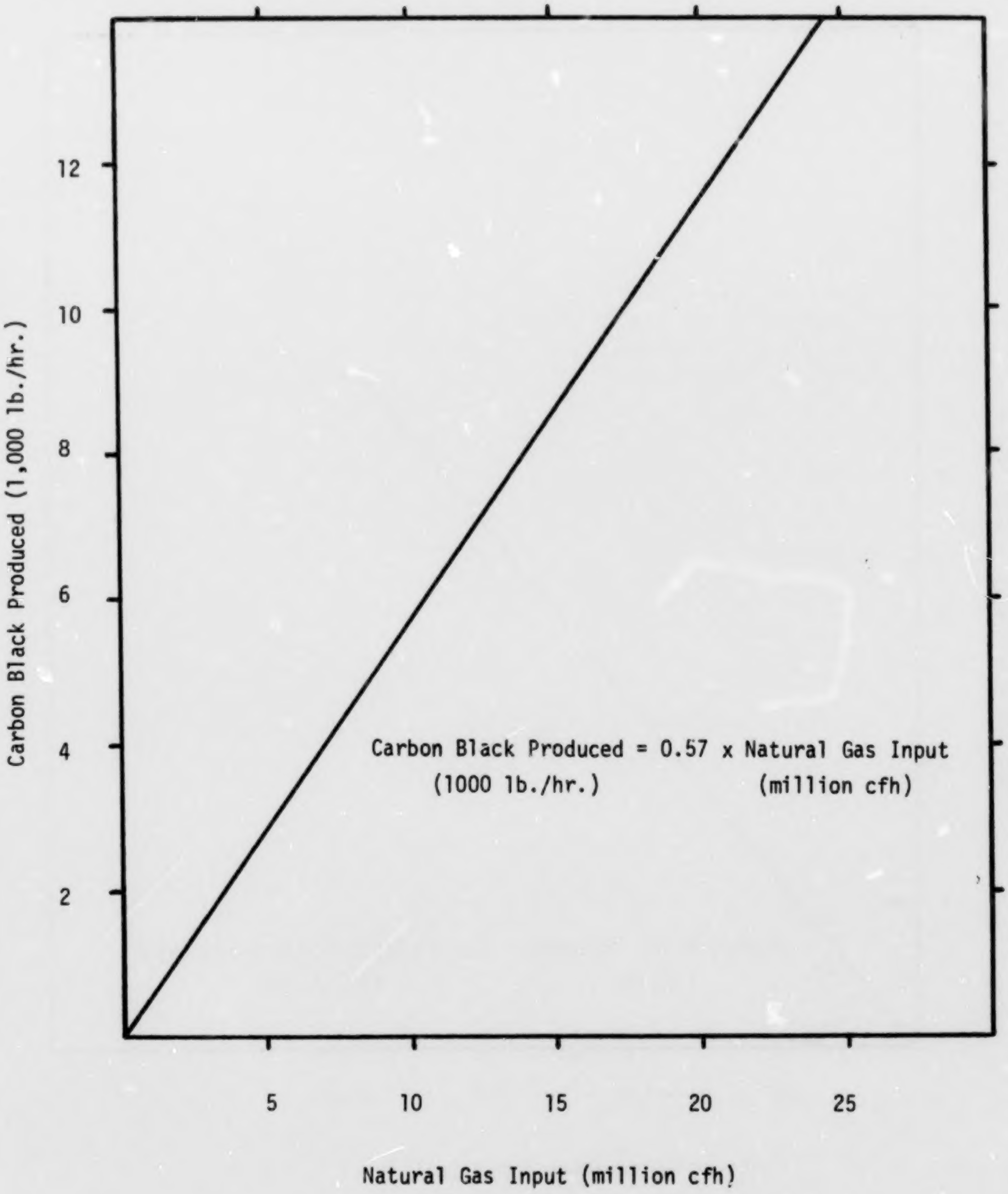


Figure IV-2.1 Average yield of carbon black from natural gas process

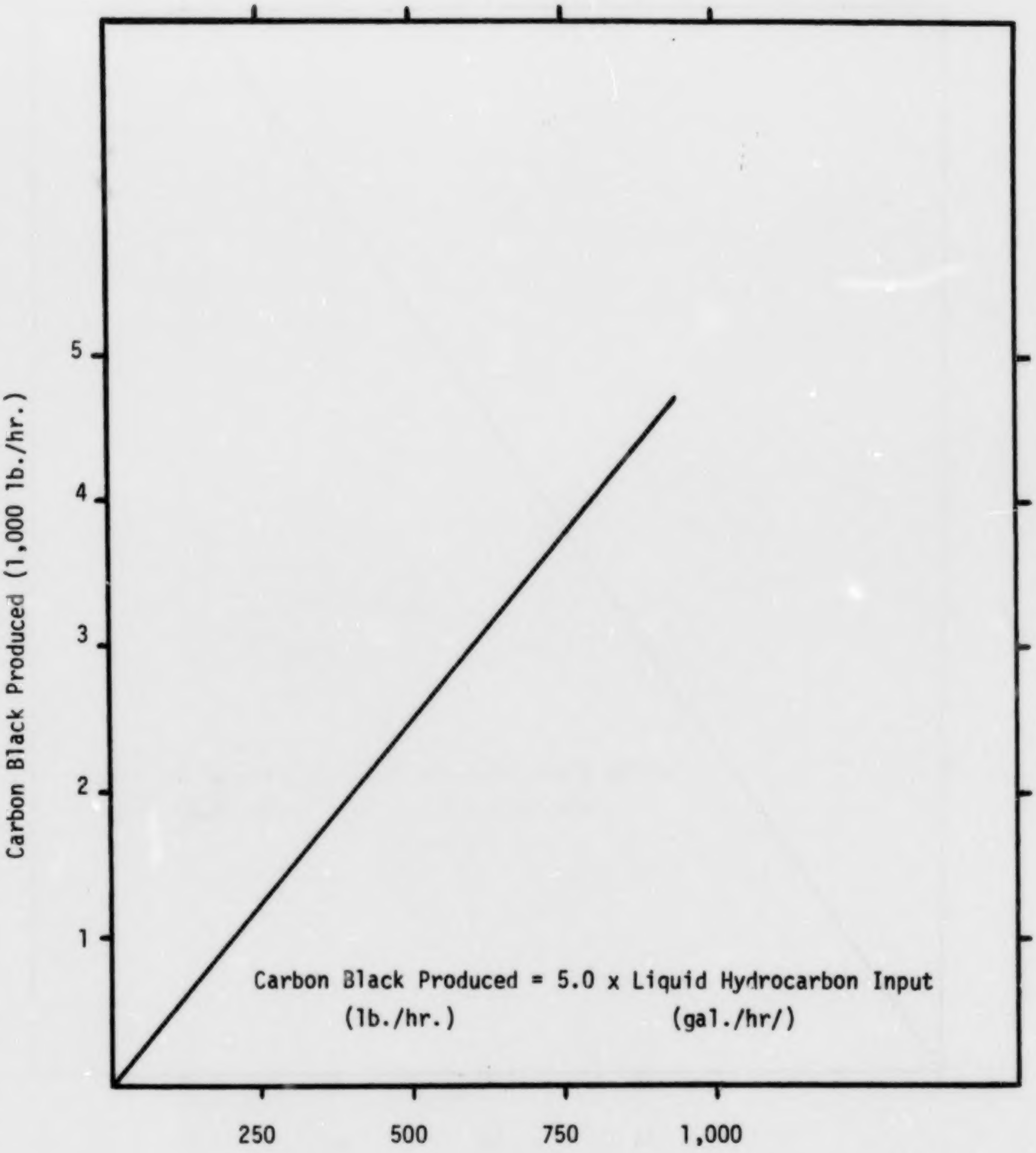
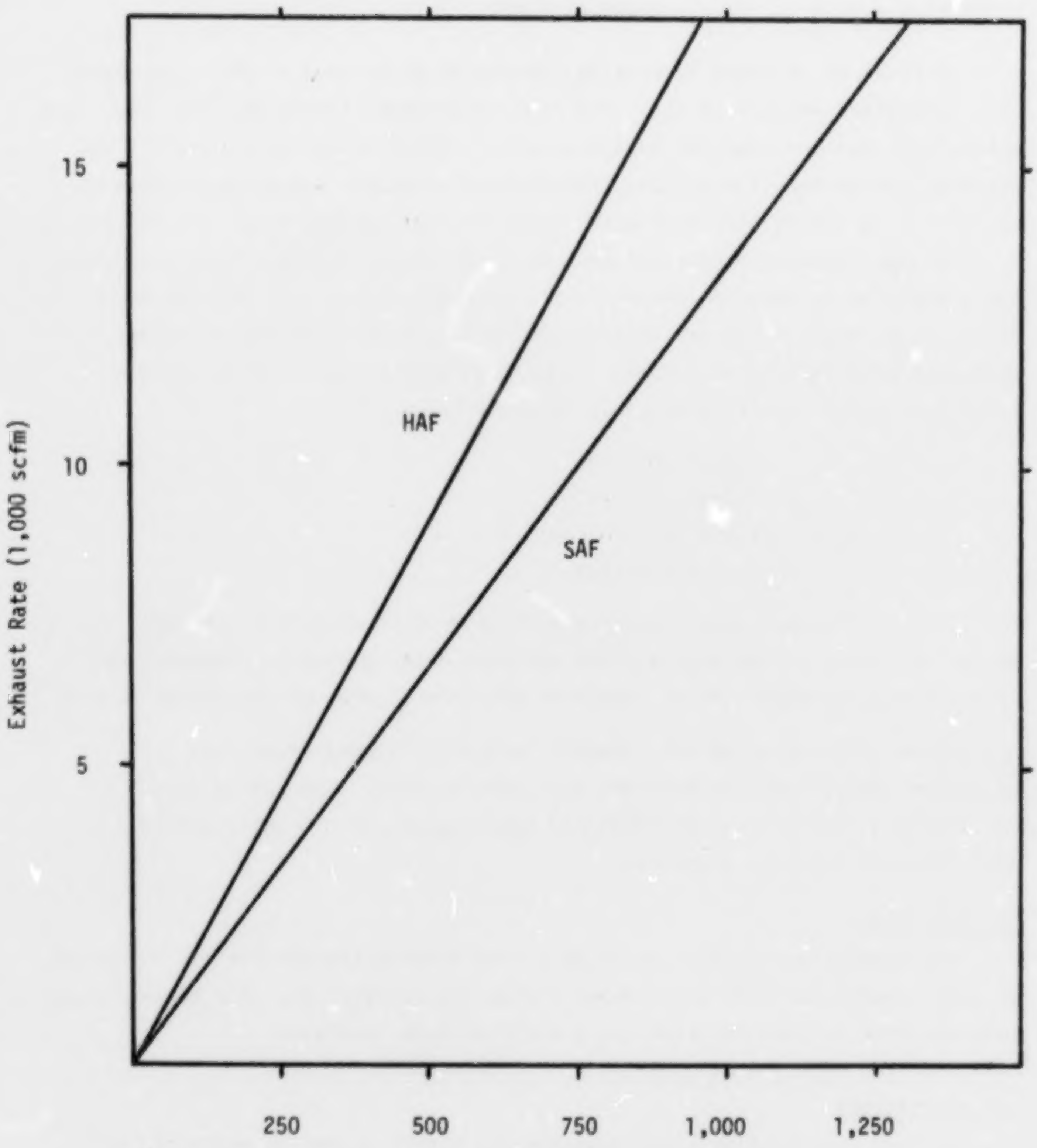


Figure IV-2.2 Average yield of carbon black from fuel oil process



Liquid Hydrocarbon Input (gal./hr.)

Figure IV-2.3 Exhaust rates for oil fired carbon black plants

CHAPTER IV-3

CHARCOAL PLANT [D]

Charcoal is produced by heating various kinds of wood in air tight ovens with controlled amounts of air. The high temperature breaks the wood down into gases, tar, and the familiar carbon residue commonly known as charcoal. The greatest use is home and outdoor recreational cooking. Annual production of charcoal is about 500,000 tons with Missouri manufacturing about 125,000 tons/year.

The most popular production unit is the concrete Missouri-Type Kiln which has a capacity of about 50 cords (128 ft.^{3}). The average kiln size is about 20 ft. wide, 30 ft. long and 10 ft. high holding between 45 and 50 cords. Operation of a typical kiln shows about 12 burns/year with each burn on a 23-25 day cycle.[6] The typical cycle is shown below:

2 days to load
7 days to burn
12-14 days to cool
2 days to unload

The yield of charcoal from a given amount of wood is dependent upon the amount of carbon in the wood and the coking process employed. However, the yield is approximately 190 lb. charcoal per cord of wood burned (Table IV-3.1).[6,7]

Since charcoal ovens are commonly located in remote areas, air pollution control devices have not been used to date. The use of an afterburner, following condensation of water vapor, to control organics from the kiln has been suggested.

GAS FLOW RATE

The production of charcoal is by a slow burning process similar to coking of coal. Emissions will occur about 7 days out of every 25. The total gaseous emission rate is 1200 cfm from the 8 ports of a 50 cord kiln.

GAS TEMPERATURE

No data were available but temperatures should be on the order of 500°F.[8]

GAS VELOCITY

The exhaust gas velocity for charcoal plants is only slightly higher than natural convection, about 10 fps.[8]

STACK HEIGHT

Figure IV-3.1 is a sketch of a typical charcoal kiln. Stacks from this kiln are tile ducts (6-8 inches in diameter) and extending 15 feet above the top of the kiln.[8]

TABLE IV-3.1

Typical Analyses of Dry Wood

	Per cent by weight				Heating value BTU per lb.		Atmos. air at zero excess air lb./10^6Btu	CO_2 at zero excess air, per cent
	Carbon	Hydrogen	Oxygen	Ash	Higher	Lower		
SOFTWOODS								
Cedar, White	48.80	6.32	44.46	0.37	8400*	7780	709	20.2
Cypress	54.98	6.54	38.08	0.40	9870*	9234	712	19.5
Fir, Douglas	52.3	6.3	40.5	0.8	9050	8438	719	19.9
Hemlock, Western	50.4	5.8	41.4	2.2	8620	8056	705	20.4
Pine, pitch	59.00	7.19	32.68	1.13	11320*	10620	702	18.7
while	52.55	6.08	41.25	0.12	8900*	8308	722	20.2
yellow	52.60	7.02	40.07	1.31	9610*	8927	709	19.2
Redwood	53.5	5.9	40.3	0.2	8840	8266	707	20.2
HARDWOODS								
Ash, white	49.73	6.93	43.04	0.30	8920*	8246	709	19.5
Beech	51.64	6.26	41.45	0.65	8760*	8151	728	20.1
Birch, white	49.77	6.49	43.45	0.29	8650*	8019	714	20.0
Elm	50.35	6.57	42.34	0.74	8810*	8171	717	19.8
Hickory	49.67	6.59	43.11	0.73	8670*	8039	712	19.9
Maple	50.64	6.02	41.74	1.35	8580	7995	719	20.3
Oak, black	48.78	6.09	44.98	0.15	8180*	7587	713	20.5
red	49.49	6.62	43.74	0.15	8690*	8037	711	19.9
white	50.44	6.59	42.73	0.24	8810*	8169	713	19.8
Poplar	51.64	6.26	41.45	0.65	8920*	8311	715	20.0

* Calculated from reported higher heating value of kiln-dried wood assumed to contain eight per cent moisture.

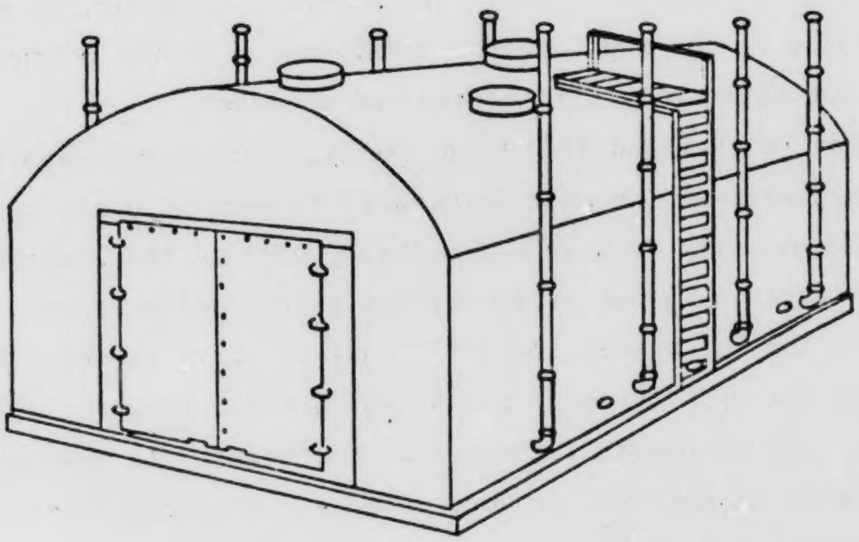


FIGURE IV-3.1 Missouri Type Charcoal Kiln

CHAPTER IV-4

CHLORINE PLANT[B]

Chlorine and caustic (NaOH) are produced concurrently by the electrolysis of aqueous sodium chloride. The production of chlorine in 1969 was 9.4 million tons from 70 plants scattered throughout the United States.[9] About 98 percent of the chlorine is produced by either the diaphragm or the mercury cell process (Figure IV-4.1). The remainder is produced as a by-product of other inorganic chemical industries. There are no major operating differences in the input-output relationship of the mercury and diaphragm cells, and hence they will be treated together.

Sodium chloride is obtained from brine wells, underground deposits of solid salt, or ocean water. The salt is usually 95 percent pure, but in most cases, it is chemically treated before being used in the electrolytic cells to prevent adverse build up of impurities in the cells. For practical purposes, the net conversion efficiency of brine to chlorine is about 50 percent for both types of cells, which means that the chlorine production rate depends on the NaCl content of the brine. In most mercury cell plants 10 percent of the NaCl is decomposed as it passes through the cell each time (Figure IV-4.2).[10] After chlorine leaves the cell it is cooled, then dried with H_2SO_4 and refrigerated into a liquid state. The production rates of chlorine plants is quoted as tons of chlorine per day.

Atmospheric emissions from both mercury and diaphram cell chlorine plants include chlorine gas, carbon dioxide, carbon monoxide, and hydrogen. Gaseous chlorine is discharged in the blow gas from the liquification step and from vents in tank cars and storage tank containers during loading and unloading. The major emission point from the chlorine plant is the liquification process. However, most plants utilize an absorption tower to catch free chlorine gas thus preventing its emission into the atmosphere. Auxillary air pollution control equipment is rarely used. Sometimes, hoods are used to ventilate storage tanks, loading areas and liquification process areas to be channeled through the absorption tower.

Chlorine plants are run continuously. Since chlorine is highly corrosive, equipment lasts only for short periods and must be repaired frequently. A plant will usually have more cells, more pumps, tanks, lines, etc., than theoretically required in order that repairs can be made without shutting down the entire production process.

GAS FLOW RATE

The liquefication process vent releases and total gas flow rates are small. From the data obtained, it would seem that plant size has little to do with volumetric flow rates (Table IV-4.1).[10] Where no specific data is available, use an exhaust flow rate of 600 scfm.

GAS TEMPERATURE

The temperatures of the exhaust gases are ambient (Table IV-4.1). Where specific data are unavailable 60°F should be assumed.

GAS VELOCITY

Since flow rates are small, stack diameters also are small. Vent stacks are usually less than 1 foot in diameter. Where specific information is unavailable, 6" diameter should be assumed and a velocity of 5-10 fps should be used for modeling calculations.

STACK HEIGHT

The stack vents generally extend above the roof line about 10 feet making a total stack height of about 50 feet.

TABLE IV-4.1

Exhaust Gases from Chlorine Plants[10]

Production Rate tons/day	Exhaust Flow scfm	Exhaust Temp. °F
240	1078	70
50	8	14
65	14.5	68
60	180	-
230	390	77
260	600	90
130	120	104
112	370	90
262	-	86
180	510	68
458	202	90

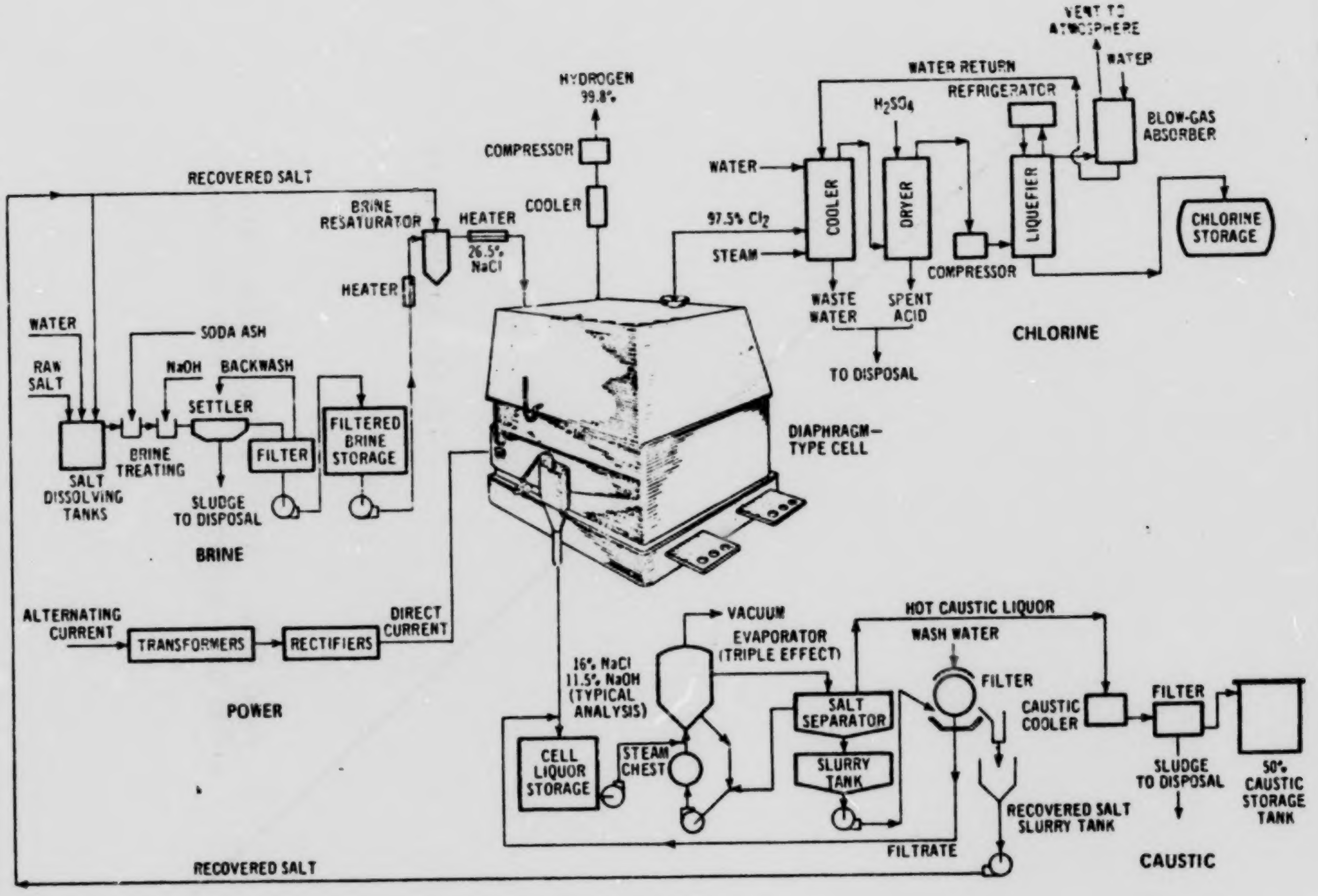

VENT TO ATMOSPHERE
WATER
WATER RETURN
REFRIGERATOR
BLOW-GAS ABSORBER
HYDROGEN 99.8%
COMPRESSOR
COOLER
H2SO4
WATER
97.5% Cl2
STEAM
COOLER
DRYER
COMPRESSOR
LIQUEFIER
CHLORINE STORAGE
WASTE WATER
SPENT ACID
TO DISPOSAL
CHLORINE
RECOVERED SALT
BRINE RESATURATOR
HEATER
26.5% NaCl
HEATER
WATER
RAW SALT
SODA ASH
NaOH
BACKWASH
SETTLER
BRINE TREATING
FILTER
FILTERED BRINE STORAGE
SALT DISSOLVING TANKS
SLUDGE TO DISPOSAL
BRINE
DIAPHRAGM-TYPE CELL
ALTERNATING CURRENT
TRANSFORMERS
RECTIFIERS
DIRECT CURRENT
POWER
VACUUM
EVAPORATOR (TRIPLE EFFECT)
HOT CAUSTIC LIQUOR
WASH WATER
16% NaCl
11.5% NaOH
(TYPICAL ANALYSIS)
CELL LIQUOR STORAGE
STEAM CHEST
SALT SEPARATOR
SLURRY TANK
FILTER
CAUSTIC COOLER
FILTER
SLUDGE TO DISPOSAL
50% CAUSTIC STORAGE TANK
RECOVERED SALT SLURRY TANK
FILTRATE
CAUSTIC
RECOVERED SALT

Figure IV-4.1. Flow diagram of a typical diaphragm cell chlor-alkali installation

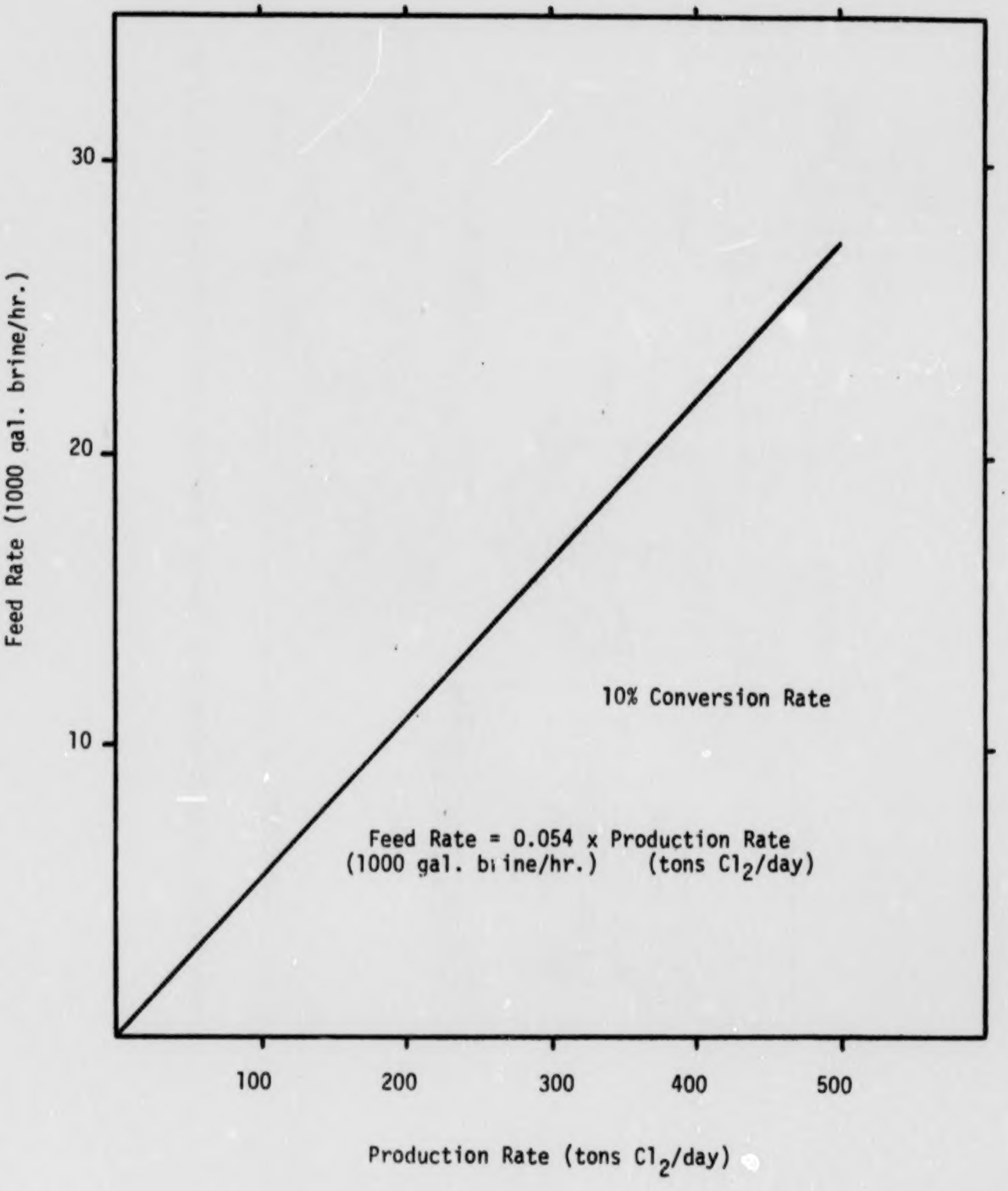


Figure IV-4.2 Feed rate as a function of chlorine plant size

CHAPTER IV-5

HYDROFLUORIC ACID PLANT[E]

The 1966 production rate for hydrofluoric acid was 244,000 tons produced by 15 plants in 10 states. Typical plant capacities range between 275 and 1,000 tons per day. Hydrofluoric acid is used mainly by the aluminum, fluorocarbon and petroleum industries. All hydrofluoric acid is manufactured by the fluorspar-sulfuric acid process (Equation IV-5.1 and Figure IV-5.1).[11]

$$\underset{\text{fluorspar}}{CaF_2} + \underset{\text{sulfuric acid}}{H_2SO_4} \longrightarrow \underset{\text{(gas)}}{2\ HF} + CaSO_4 \qquad \text{IV-5.1}$$

From Equation IV-5.1 it can be seen that about 2 pounds of fluorspar and 2½ pounds of sulfuric acid are necessary to make 1 pound of hydrofluoric acid gas. Since the product, HF, is liberated as a gas, the entire process is closed and good air pollution control serves as an economic benefit, in preventing product loss. All plants, therefore, have good air pollution control equipment. The main emission point is from the scrubber which collects water vapor and dusts, liberated from heated rotary kilns (kilns are about 55 feet long and 8 feet in diameter). Another emission point is the exit tail gases (Figure IV-5.1) where limited amounts of HF, SO_2 and CO_2 are emitted after passing through several absorption towers. Operational times for hydrofluoric acid plants are continuous.

GAS FLOW RATE

The exhaust flow data from one plant was 15 scfm. Flow rates from hydroflouric acid plants are not expected to exceed 1000 scfm.[12]

The exhaust flow rate from the kiln is expected to be about 5,000 scfm. No data were available.[12]

GAS TEMPERATURE

No data were available, but exit temperatures are expected to be between 80 and 180°F. One plant reported 85°F. For calculation purposes use 120°F.

GAS VELOCITY

Low velocities are expected at the tail gas outlet. Assume 10 fps for calculation purposes.

STACK HEIGHT

No data were available on hydrofluoric acid stack heights. A typical range for other chemical processes is 100 - 200 feet. Use 150 feet for modeling.

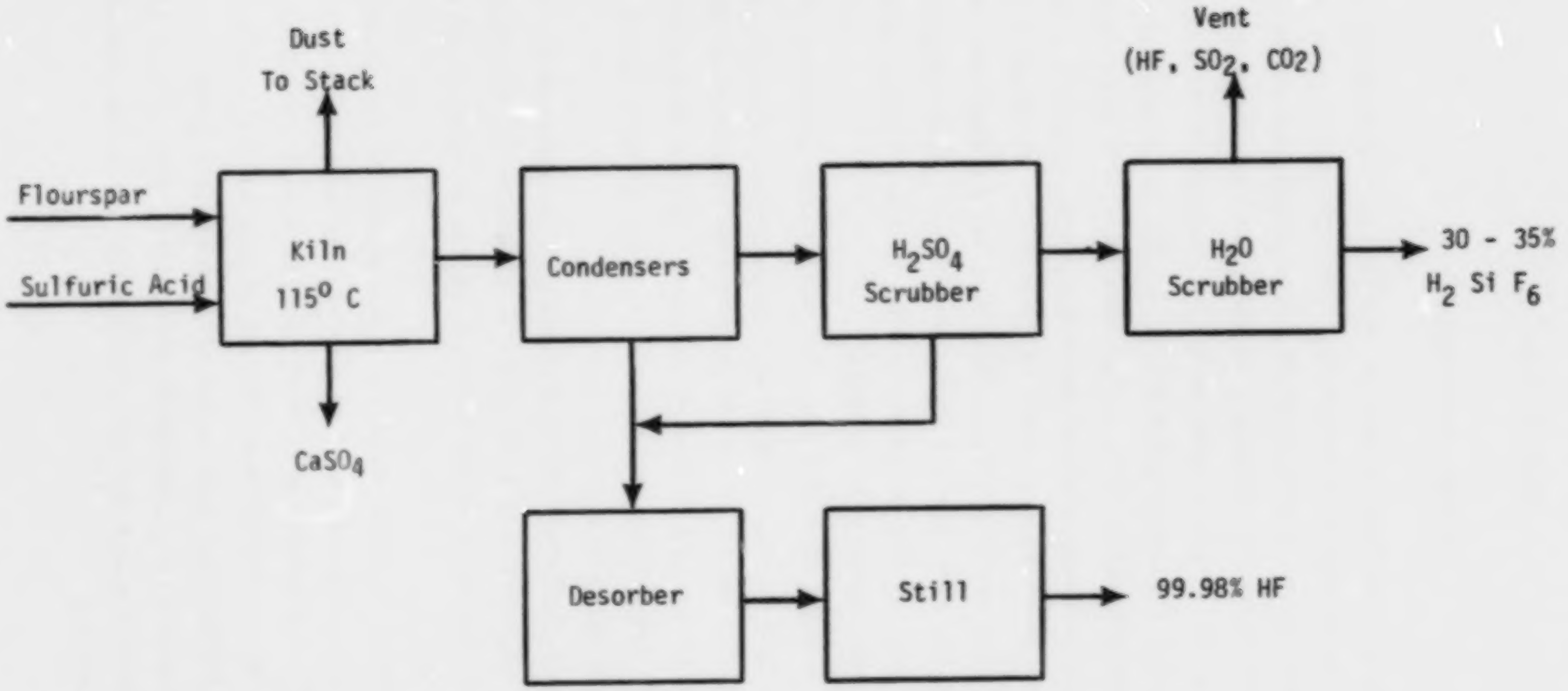

Dust
To Stack
Flourspar
Sulfuric Acid
Kiln
115° C
CaSO4
Condensers
H2SO4
Scrubber
Vent
(HF, SO2, CO2)
H2O
Scrubber
30 - 35%
H2 Si F6
Desorber
Still
99.98% HF

Figure IV-5.1 Flow diagram of the flourspar-sulfuric acid process for the manufacture of hydroflouric acid.

CHAPTER IV-6

NITRIC ACID PLANT [A]

There are about 75 working plants in the United States which produce over 5 million tons of nitric acid annually. The government owns emergency plants which are operated only when needed. The plants are scattered about the country since the chief raw material is ammonia which is widely available. Nitric acid is principally used in the production of fertilizer. Other uses include commercial explosives, rocket fuels and industrial applications.

There are three processes used to manufacture nitric acid: pressure process, intermediate pressure process and atmospheric pressure process. The chemistry behind each of these processes is identical. Although the emission rates may vary from process to process, the input output function and exit flow rates are about the same for the three processes. Approximately 90% of the nitric acid is made by the pressure process. Older plants built before 1910 generally used the atmospheric process.

Anhydrous ammonia gas is mixed with hot air in the presence of a platinum catalyst to form nitrogen oxide and then further oxidized to nitrogen dioxide. NO_2 reacts with water in an absorption tower to produce HNO_3 with concentrations normally between 50 and 60 percent. Figure IV-6.1 shows the flow diagram of a 120 ton-per-day nitric acid plant utilizing the pressure process. These plants operate 24 hours per day.

The principal air pollutant emissions are the unconverted nitrogen oxides. Almost all nitric acid plants have, in addition to the absorber tower, catalytic fume abatement equipment (15% of the plants) or an alkaline scrubbing system (85%).

The three processes require about the same amount of raw material, 100 percent ammonia and preheated air, to produce the same amount of nitric acid (Figure IV-6.2).[13] New plants will tend to have a more efficient absorption tower and hence require not as much of the raw materials. In general 1 pound of ammonia feed rate input will generate 8 pounds of 50 percent HNO_3 output. Figure IV-6.2 indicates that nitric acid plants adhere closely to design specifications and the recommended operating procedures since little variation is evident.

GAS FLOW RATE

Since air requirements are the same for all three processes, the exhaust flow rates are also proportional even though some plants have gas treatment equipment. Figure IV-6.3 indicates that nitric acid manufacturers adhere closely to the engineered operating procedures which have few operating variables. In general the gas flow rate will be about 80 scfm per ton/day HNO_3. See Table IV-6.1.[13,14]

GAS TEMPERATURE

Exit gas temperatures are independent of the manufacturing processes. The major factor affecting stack temperature is the abatement equipment being used. The catalytic oxidizers create slightly higher exhaust temperatures. The stack exit temperature from the catalytic oxidizer control systems is about $450^{o}F$. When no abatement equipment is used, the temperature will range from 75 to $120^{o}F$ and a temperature of $80^{o}F$ should be assumed as average.

GAS VELOCITY

Most nitric acid plants are designed to diffuse the stack emissions as much as possible. The trend today is toward tall stacks to aid in the dispersion of the nitrogen oxide gases. Increased temperature and velocity of the gases increase effective stack height and further aid dispersion. One plant in the United States uses a venturi device on top of a tall stack to increase exit velocity and bring about greater dilution. The stack diameters range from 3 to 8 feet and velocities range from 40 to 60 fps.

STACK HEIGHT

Most nitric acid plants have stack heights between 150 and 250 feet. New plants tend to have taller stacks for added dilution, which run about 350 feet.

TABLE IV-6.1

Exhaust Gases from Nitric Acid Plants [13,14]

Production Rate tons/day	Ammonia Input Rate 1000 lb./hr.	Exhaust Flow 1000scfm	Exhaust Temp. °F	
			before	after
No Waste Gas Treatment				
60	1.454	5.3	450	
120	2.750	10.5	450	
120	2.750	10.5	450	
120	2.750	10.0	450	
120	2.750	10.0	450	
180	4.000	15.5	450	
200	4.740	16.5	450	
265	6.670	21.8	450	
750	18.750	57.6	450	
700	17.500	59.0	-	
Catalytic Waste Gas Treatment				
110	3.346	10.9	840	1250
120	2.880	9.3	375	915
140	3.500	11.3		1500
150	3.675	11.7	502	1120
170	4.100	13.7	250	900
185	4.471	14.5	660	1190
230	6.670	20.5	570	930
350	8.460	28.6		1250

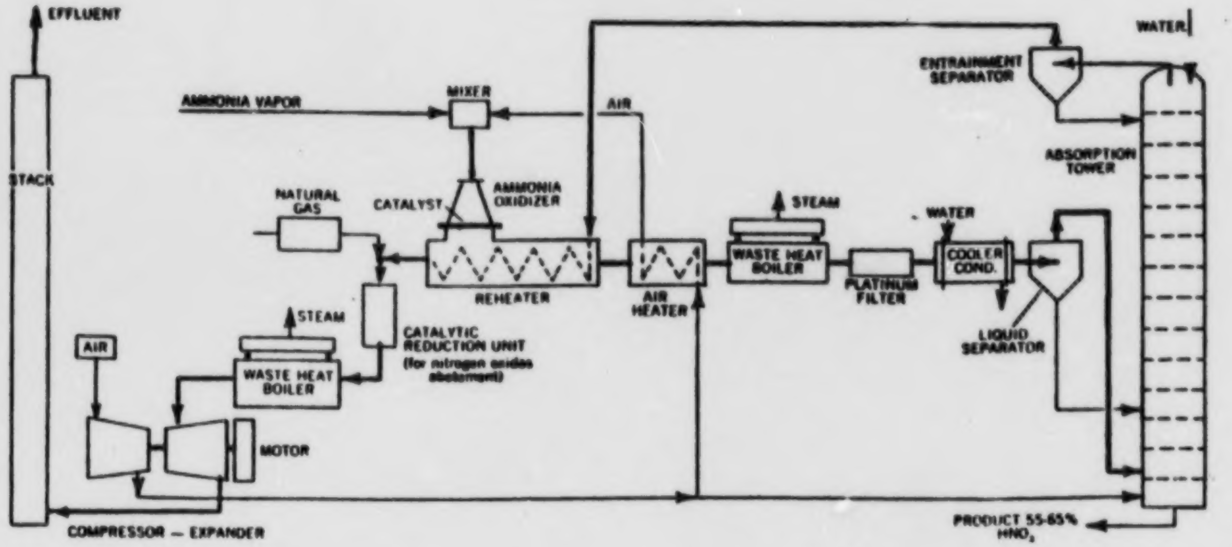
TABLE IV-6.1 (Continued)

Exhaust Gases from Nitric Acid Plants

Production Rate tons/day	Ammonia Input Rate 1000 lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F before	after
Catalytic Waste Gas Treatment (cont.)				
140	3.500	11.3	-	
220	6.150	20.0	-	
280	6.800	21.2	-	
340	8.600	27.1	-	
Alkaline Scrubbers				
50	1.200	3.5	-	
120	2.900	8.9	-	

FIGURE IV-6.1

FLOW DIAGRAM FOR NITRIC ACID PRESSURE PROCESS


EFFLUENT
AMMONIA VAPOR
MIXER
AIR
ENTRAINMENT SEPARATOR
WATER
STACK
ABSORPTION TOWER
NATURAL GAS
CATALYST
AMMONIA OXIDIZER
STEAM
WATER
REHEATER
AIR HEATER
WASTE HEAT BOILER
PLATINUM FILTER
COOLER COND.
STEAM
CATALYTIC REDUCTION UNIT (for nitrogen oxides abatement)
LIQUID SEPARATOR
AIR
WASTE HEAT BOILER
MOTOR
PRODUCT 55-65% HNO₃
COMPRESSOR — EXPANDER

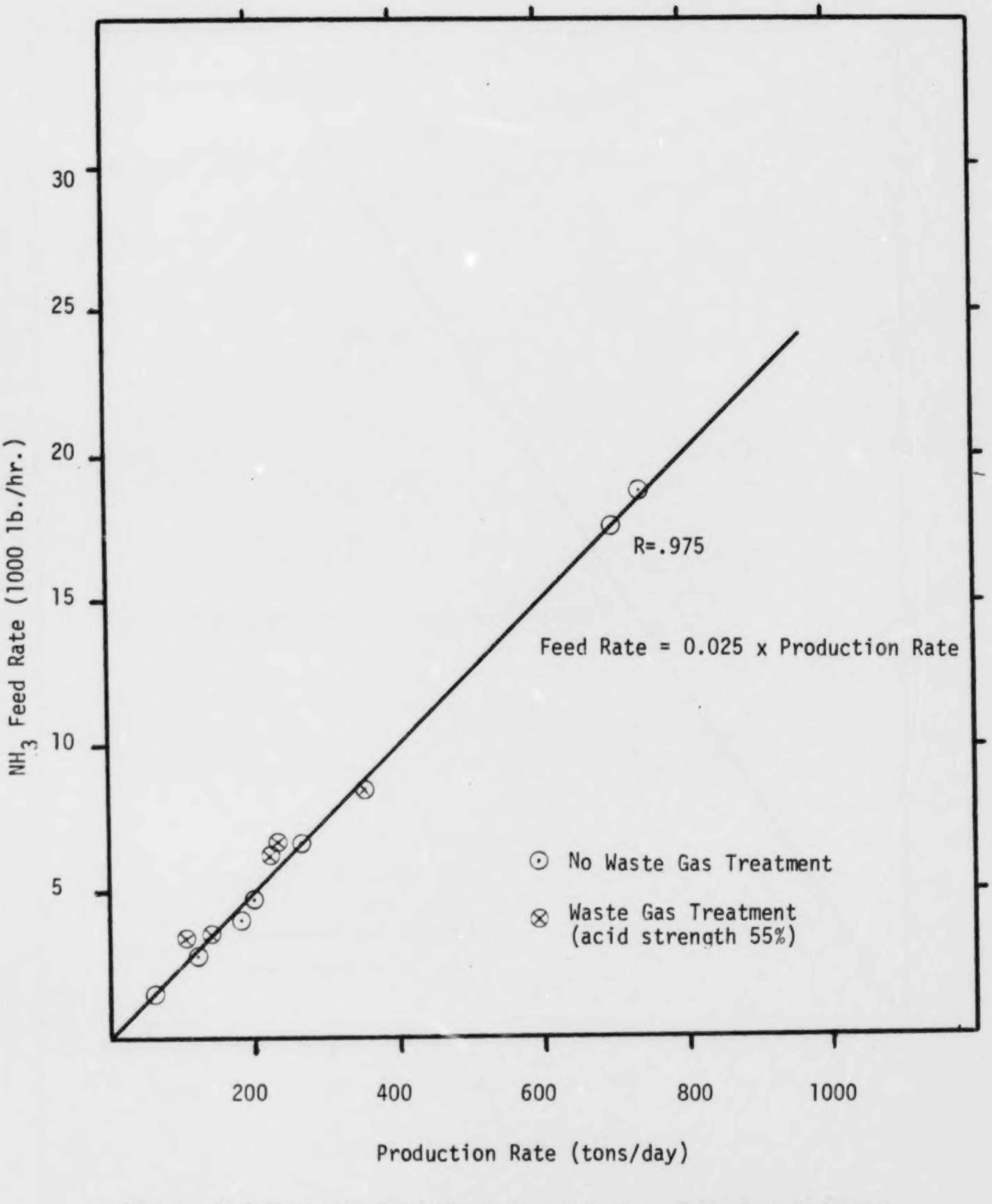


Figure IV-6.2 Nitric Acid Plant Capacity as a Function of Ammonia Feed Rate.

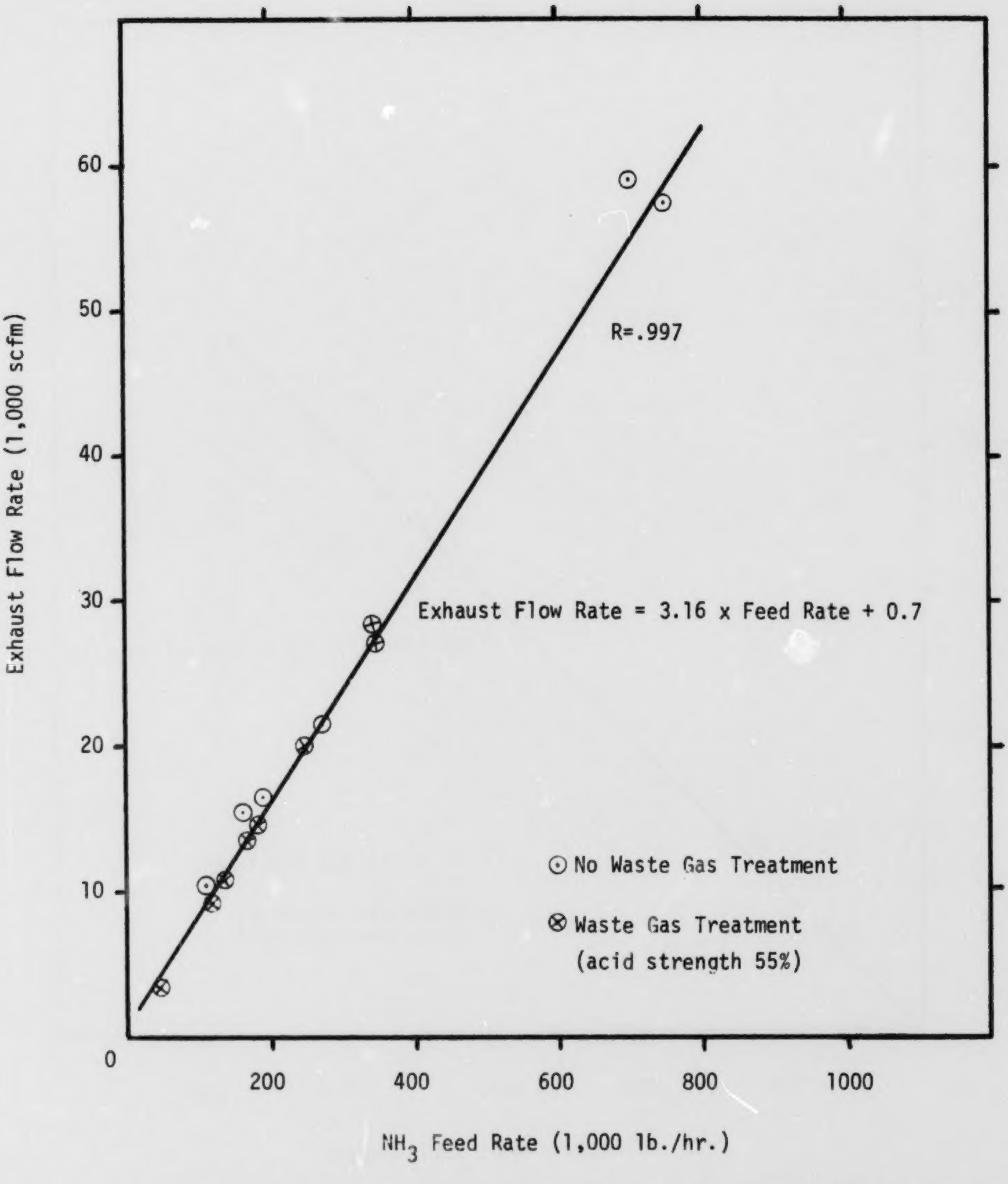


Figure IV-6.3 Exhaust flow rates at various feed rates in the production of Nitric acid.

CHAPTER IV-7

PAINT AND VARNISH PLANT [B]

In 1963 there were 1,800 paint and varnish manufacturers in the U. S. consuming as many as 2000 different raw materials. Because of the variety of raw material input to these plants and wide commercial distribution of finished products, paint and varnish plants are scattered throughout the U. S.

The manufacturing processes of paint and varnish are closely related since paint is, with some modifications, a pigmented resinless varnish. With the exception of paint pigment and varnish resin, the raw materials for paints and varnishes are the same: oils and/or thinners, antiskimming agents to prevent gelling, additives to increase the drying rate and plasticizers to minimize cracking of the dried film.[15] Paint pigments may be either organic or inorganic dyes; varnish resins may be natural or synthetic. The production process for paint (Figure IV-7.1) includes the assembling, weighing and mixing of pigments and oils which are fed into a grinding mill to produce a smooth product. The paint is then thinned and filtered to remove nondispersed pigments. Varnish production differs from paint production in that a resin depolymerization step replaces the mixing step in paint production. Depolymerization is accomplished by heating resin to 550 - 650°F until the desired viscosity is obtained. The product is cooled and transferred to the thinning tank where final ingredients (dryers, plasticizers, etc.) are added.[15,16]

Air pollution emissions from paint production are of two types: particulates, from handling the pigments and fillers prior to mixing, and organic vapors from the oils and thinners used in the mixer and thinning tanks. These emissions are controlled with either scrubbers or afterburners. Emissions from varnish production are greater because of the heat required in the depolymerization reaction. This reaction takes place in either open or closed varnish cooking kettles, varying in capacity from 100 to several thousand gallons. Closed kettles generate few emissions, but open kettles emit significant quantities of acrolein and other odorous compounds and particulates. These emissions may be efficiently controlled through use of wet scrubbers or afterburners.

GAS FLOW RATE

Exhaust flow rates (Table IV-7.1) ranged from 600 to 3050 scfm with a mean of 1200 scfm for 200 gal./hr. mixers and 320 to 950 scfm and a mean of 650 scfm for kettles.[17,18] As flow rates may vary from plant to plant, actual data should be used when available for caluclations. The above air flows equate to 6 scfm per gal./hr. of paint produced and 0.5 scfm per gal./hr. of varnish produced.

GAS TEMPERATURE

If no control equipment is employed, stack gas temperature will be essentially the ambient temperature for mixers and 140°F for kettles. When an afterburner type control is used, stack gas temperatures will be about 1150°F.

GAS VELOCITY

The exit velocity for mixers and kettles was about 15 fps. Because of the low flow rates, velocities would not usually exceed 20 fps, therefore, use 15 fps.

STACK HEIGHT

From available data all stack heights were below 50 feet. If no actual data are available, use a 40 ft. stack height for calculations.

TABLE IV-7.1

Exhaust Gases from Paint and Varnish Plants[17,18]

Mixers

Input Rate gal./hr.	Exhaust Flow scfm	Exhaust Temp. ^oF.	Stack Height ft	Stack Diameters ft	Operating Time
85	3050	Ambient	4	1.2	6 hrs/cyc, 250 cyc/yr,
105	3050	Ambient	4	1.2	6 hrs/cyc, 250 cyc/yr
80	700	Ambient	25	0.5	24 hrs/cyc, 250 cyc/yr
88	700	Ambient	25	0.5	24 hrs/cyc, 250 cyc/yr
113	670	Ambient	50	0.5	1.5 hrs/cyc, 500 cyc/yr
267	600	Ambient	50	0.5	1.5 hrs/syc, 1500 cyc/yr
433	600	Ambient	50	0.5	1.5 hrs/cyc 1500 cyc/yr
316	740	Ambient	50	0.5	1.5 hrs/cyc 1500 cyc/yr
436	670	Ambient	50	0.5	1.5 hrs/cyc 1500 cyc/yr
Avg 214	1198	Ambient	34	0.65	7.5 hrs/cyc 833 cyc/yr

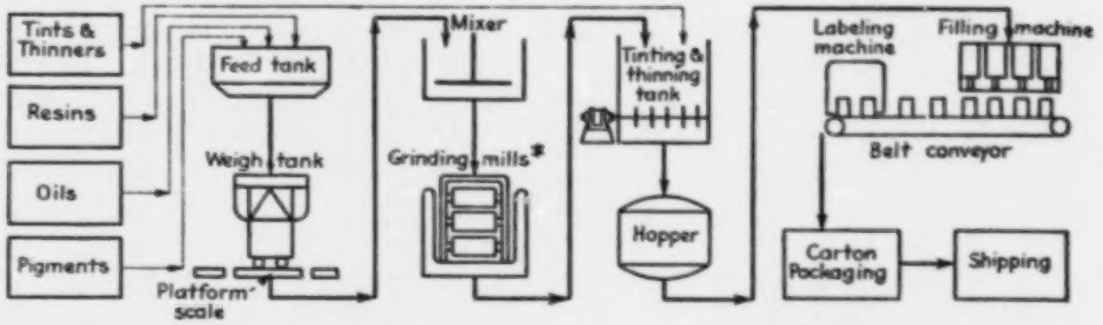
TABLE IV-7.1

Exhaust Gases from Paint and Varnish Plants[17,18]

Kettles

Input Rate gal./hr.	Exhaust Flow scfm	Exhaust Temp. ^oF.	Exit Velocity fps	Stack Height ft	Stack Diameter	Operating Time
102	670	170		50	0.5	1 hr/cyc, 1000 cyc/yr
550		A		40	0.6	12 hrs/cyc, 300 cyc/yr
1000		150		50	2.5	12 hrs/cyc, 250 cyc/yr
2000		110		50	3.0	6 hrs/cyc, 50 cyc/yr
3000/2		150		50	3.0	12 hrs/cyc, 250 cyc/yr
	950	1,220	15			
	320	1,100	12			
Avg 1109	647	423	13	48	1.9	8.6 hrs/cyc, 370 cyc/yr.

FLOWCHART FOR MIXING OF PAINT


Tints & Thinners
Resins
Oils
Pigments
Feed tank
Weigh tank
Platform scale
Mixer
Grinding mills*
Tinting & thinning tank
Hopper
Labeling machine
Filling machine
Belt conveyor
Carton Packaging
Shipping

NOTE: Because a complete paint factory consumes upward of 2000 different raw materials and produces ten times as many finished products, it is not possible to gives yields, etc.

* Many types of grinding mills are used in the same plant either in series or in parallel. Some of them are: buhrstone, coffee, and single-, three-and five-roll steel mills

CHAPTER IV-8

PHOSPHORIC ACID PLANT [B]

Production of phosphoric acid approaches a rate of 5 million tons per year. Phosphoric acid is a raw material to the fertilizer industry and to the food, drug and detergent users. Each user requires different concentrations of H_3PO_4 for its particular application which almost mandates a "custom house" product. Instead of new plants being built, existing plants have been modified to meet increasing demands. There are about 80 phosphoric acid plants in the United States with no particular significance to geographic locations.

Phosphoric acid is produced in one of two ways: wet process manufacture or thermal process manufacture. The wet process manufacture is oldest and cheapest. Since the processes operate differently, each will be presented independently to provide a comprehensive analysis.

"Wet Process"[19]

Phosphoric acid obtained through the wet process is used in the manufacture of phosphate fertilizer. Figure IV-8.1 shows a diagram of the wet process manufacturing plant. In this process phosphate rock containing fluorapatite, $Ca_{10}(PO_4)_6F_2$, is ground and mixed with concentrated sulfuric acid to produce phosphoric acid. A 32 percent available P_2O_5 fluorapatite will make a final solution of 54 percent phosphoric acid. Capacity of phosphoric acid plants is usually given in tons/day of P_2O_5. Equation IV-8.1 may be used to calculate the amount of raw fluorapatite used to make phosphoric acid assuming that the fluorapatite contains 32 percent P_2O_5 (narrow range between 31-35.5 percent) and the phosphoric acid is concentrated to 54 percent in the final stage.

$$\text{Fluorapatite input (lb./hr.)} = \text{lb. } H_3PO_4\text{/hr.} \times 2.33 \qquad \text{IV-8.1}$$

Principal air pollutants from phosphoric acid plants are gaseous fluoride and fluoride particulates from the digester, evaporator and the filter (Figure IV-8.1). The evaporator in a sense is an air pollution control device; however, additional scrubbers are used on most plants. Emissions from the digester and filter are collected with the use of hoods and vented to collectors. Commonly used venturi scrubbers have collection efficiency ranges from 85 to 95 percent for the gaseous fluoride emissions and almost 100 percent efficiency for particulates.

The production of phosphoric acid is a continuous process and therefore runs 24 hours a day.

GAS FLOW RATE

Exhaust flow rates depend entirely on air pollution control ducting and ventilation configuration (Figure IV-8.2). Some plants only control emissions from the digester while others control emissions from all three sources, digester, filter and evaporator. The plants often combine gases from the digesters, filters, hoods and send them to a common collection device like the scrubber. The figure and Tables IV-8.1,8.2, and 8.3 show flow rates coming from the digester between 10 and 50 scfm per ton/day of acid produced and 60 scfm per ton/day for the filter hood.[19] Gas flow from the evaporator generally represents a very small portion of the total plant exhaust. Combined exhaust flows showed 8,500 scfm for a 150 ton/day plant or 57 scfm per ton/day of acid production.

GAS TEMPERATURE

Since most of the gas entering the scrubber systems comes from hoods over the filter and digester in the plant, exhaust gas temperature will be near ambient conditions. Data for 12 digesters showed temperatures between 75 and 160°F; for the scrubber exhausts, 85° to 95°F was reported; filter hoods, towers and combined exhausts ranged from 80 - 102°F; 100°F should be assumed as typical.

GAS VELOCITY

Since the diameter of the stacks was not known for any of the plants where other data were obtained, no gas velocities could be calculated. Where specific data are unavailable 30 fps should be assumed.

STACK HEIGHT

The stacks on phosphoric acid plants are usually less than 3 feet in diameter, brick or rubber lined to prohibit corrosion, and short (between 5 and 20 feet above the roof of the plant). Therefore total stack height would be expected to range from 30 - 60 feet averaging about 50 feet.

"Thermal Process"[20]

The thermal process accounts for about one third of the Nation's phosphoric acid production. This acid is used to produce high quality phosphates for the food, drug, and detergent industries. The cost is nearly twice the cost of H_3PO_4 produced by the wet process. Most plants produce 75 to 80 percent phosphoric acid but some can produce 115 percent H_3PO_4 (Figure IV 8.5).

Figure IV-8.3 shows a schematic diagram for manufacture of phosphoric acid by the thermal process method. Raw materials for this method include elemental (yellow) phosphorous, air and water. Phosphorous is usually handled in the molten state at the plant site. It is mined from the ground and processed into a molten state by electric furnaces. The phosphorous is burned and water is added to the combustion gases and later collected in the hydrator-absorber.

Air pollution emissions are principally the H_3PO_4 mist, since the hydrator absorber is not a perfect collector of the acid mist. Depending on end use, other chemicals may be added which may or may not give additional emissions. For example, sodium hydrosulfide is often added to the phosphoric acid that is used in the food industry. All thermal process phosphoric acid plants have abatement equipment. Venturi scrubbers, packed scrubbers, glass fiber mist eliminators, wire mesh mist eliminators and electrostatic precipatators are commonly used as control equipment.

The production of phosphoric acid is a continuous process and operates at all times of the day and year with no particular fluctuation in the process.

The chemical reactions necessary to produce H_3PO_4 are:

$$P_4 + 5O_2 \xrightarrow[\text{heat}]{3000^\circ} P_4O_{10} \quad \text{and} \quad P_4O_{10} + \overset{6}{H_2O} \xrightarrow{\text{steam}} 4H_3PO_4 .$$

One pound of phosphorous will make about 3.2 pounds of phosphoric acid. The concentration of H_3PO_4 is always expressed as percent P_2O_5. Assuming that raw phosphorous is in a near pure (100% P_4) molten state. Equation IV-8.2 can be used to determine the amount of phosphorous input.

$$\text{Raw phosphorous input (lb./hr.)} = \frac{\text{production rate (lb./hr.)} \times 0.725}{4 \times (\%H_3PO_4)} \qquad \text{IV-8.2}$$

GAS FLOW RATE

Exhaust gases are derived from the combustion of phosphorous and the addition of steam into an enclosed system. Figure IV-8.4 shows a linear relationship with little variation which is attributed to the closed system. Exhaust flow will be a little over 2.0 scfm for every 1 lb./hr. of phosphorous feed. Typical flow rates are 5,000 - 20,000 scfm for these plants.

GAS TEMPERATURE

Table IV-8.4 indicates exhaust temperatures and plant capacities for twenty-five plants. Where specific data are unavailable, 170°F should be assumed as average since the temperature is consistently between 117 and 201°F.

GAS VELOCITY

No data were available, but since flow rates from the thermal process are relatively small (5,000 - [illegible]0,000 scfm), the velocities are not expected to be high. Where data are unavailable 30 fps may be assumed.

STACK HEIGHT

No data were available but stack heights are determined by the air pollution control system configuration. When specific data from phosphoric acid plants is not available a stack height of 50 feet should be used for modeling purposes.

TABLE IV-8.1

Exhaust Gases from Wet Process[19]

Phosphoric Acid Plant Digesters

Production Rate tpd P_2O_5	Exhaust Flow 1000 scfm	Exhaust Temp. $^oF.$
107.5	3.8	160
107.5	3.9	160
107.5	4.0	160
156	7.7	75
156	7.7	75
156	7.5	75
130	1.8	130
130	2.1	130
130	1.8	135
639	5.4	84
639	5.4	84
639	5.4	84

TABLE IV-8.2

Exhaust Gases from Wet Process [19]

Phosphoric Acid Plants
Scrubbers

Production Rate tpd P_2O_5	Exhaust Flow 1000 scfm	Exhaust Temp. °F.
1080	17.0	
1080	17.0	
1080	17.0	
400	40.8	85
400	40.8	85
400	40.8	85
745	30.2	95
745	30.2	95
745	30.2	95

TABLE IV-8.3

Exhaust Gases from Wet Process[19] Phosphoric Acid Plant Sources

Production Rate tpd P_2O_5	Exhaust Flow 1000 scfm	Exhaust Temp. °F.
Filter Hood:		
107.5	6.1	80
107.5	6.7	80
107.5	6.6	80
All (Digester, Scrubber Filter hood)		
150	8.7	102
150	8.7	102
150	8.7	102
Tower		
103	15.6	90
103	15.6	90
103	15.6	90

TABLE IV-8.4

Exhaust Gases from Thermal Process Phosphoric Acid Plants[20]

Based on 85% Acid

Production Rate tons/day	Input Rate 1000 lb/hr	Exhaust Flow 1000 scfm	Exhaust Temp. °F.
116	2.59	7.0	176
116	2.60	7.9	189
116	2.60	7.0	175
359	8.64	22.0	180
127	2.87	9.9	176
166	3.75	12.9	170
179	4.00	10.0	184
178	4.00	13.9	176
97	2.25	6.4	150
268	5.70	13.2	150
88	2.00	5.0	175
170	3.95	7.5	175
268	6.00	7.0	142
238	5.30	6.7	201
309	7.00	15.8	168

TABLE IV-8.4

Exhaust Gases from Thermal Process Phosphoric Acid Plants, Continued [20]

Based on 85% Acid

	Production Rate tons/day	Input Rate 1000 lb/hr	Exhaust Flow 1000 scfm	Exhaust Temp. °F.
	178	4.00	18.0	165
	106	2.60	5.1	185
	177	4.03	6.2	180
	53	1.50	3.5	136
	221	5.00	17.3	170
	456	11.00	30.7	165
	NA	11.10	19.8	182
	358	8.00	12.4	172
	106	2.27	8.8	175
	132	3.00	3.7	117
Average	191	4.63	9.9	169

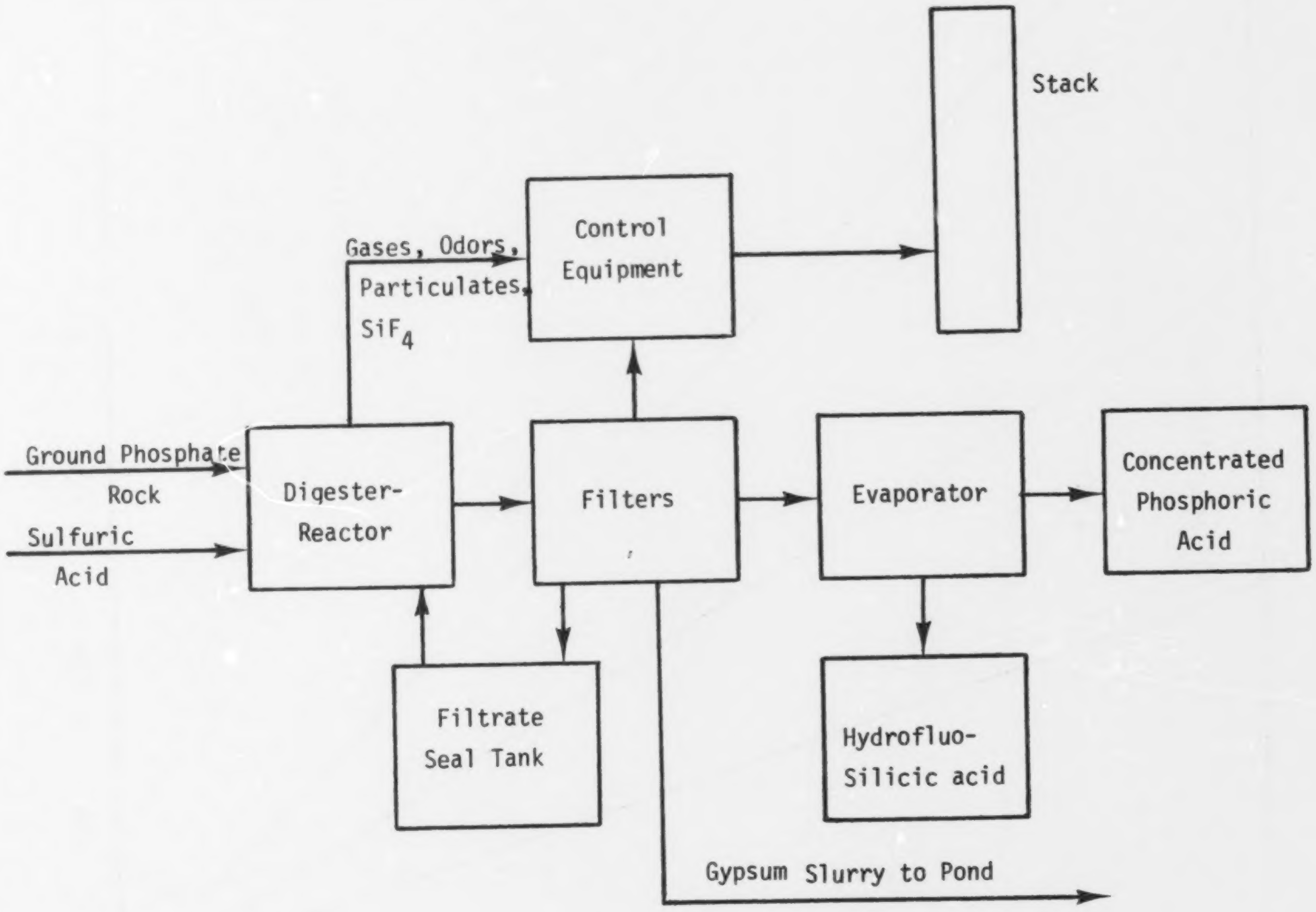

Stack
Gases, Odors,
Particulates,
SiF4
Control Equipment
Ground Phosphate Rock
Sulfuric Acid
Digester-Reactor
Filters
Evaporator
Concentrated Phosphoric Acid
Filtrate Seal Tank
Hydrofluo-Silicic acid
Gypsum Slurry to Pond

Figure IV-8.1 Flow diagram illustrating a wet-process phosphoric acid plant

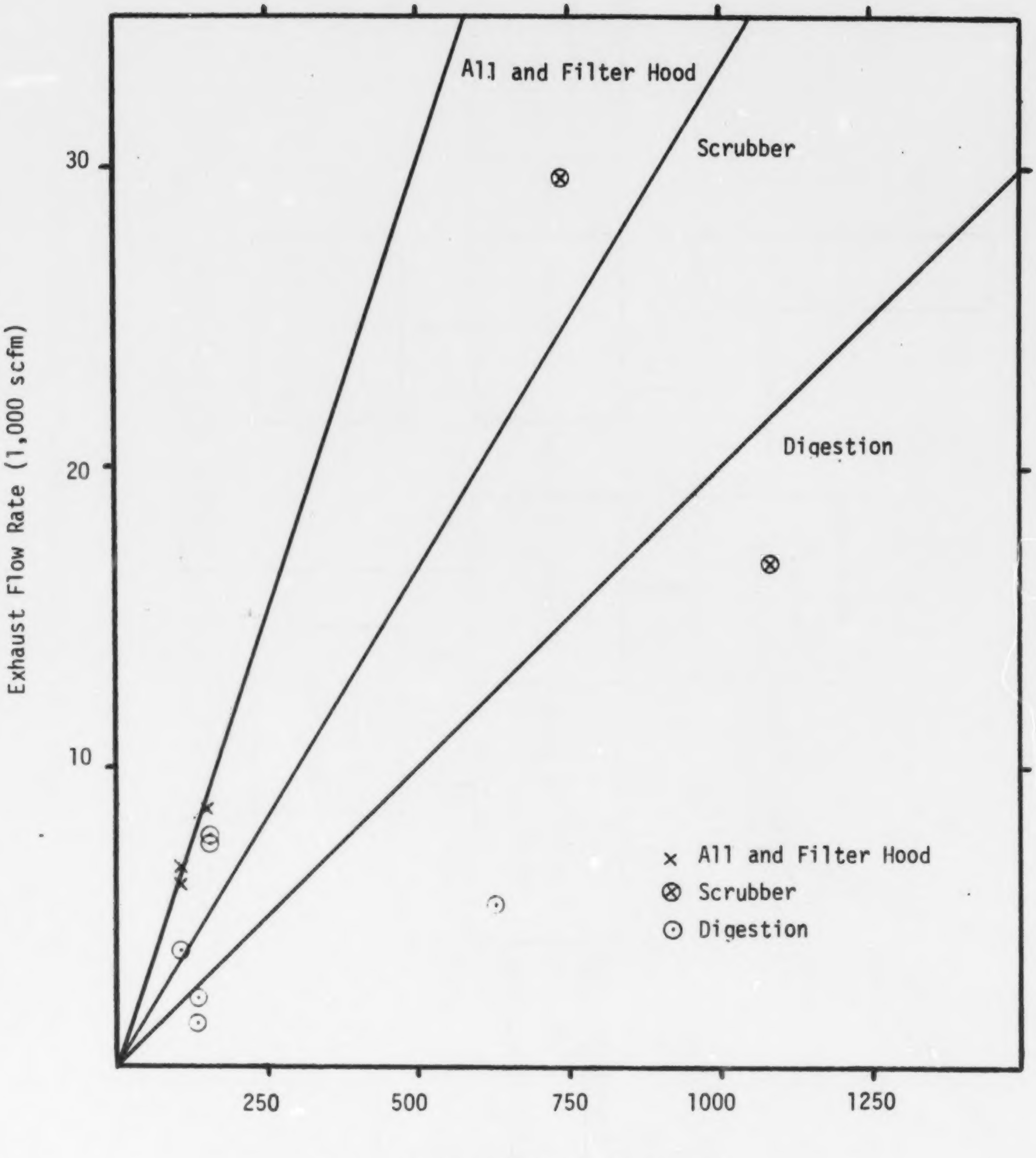


Figure IV-8.2 Exhaust flow rate vs. production for wet process phosphoric acid plant

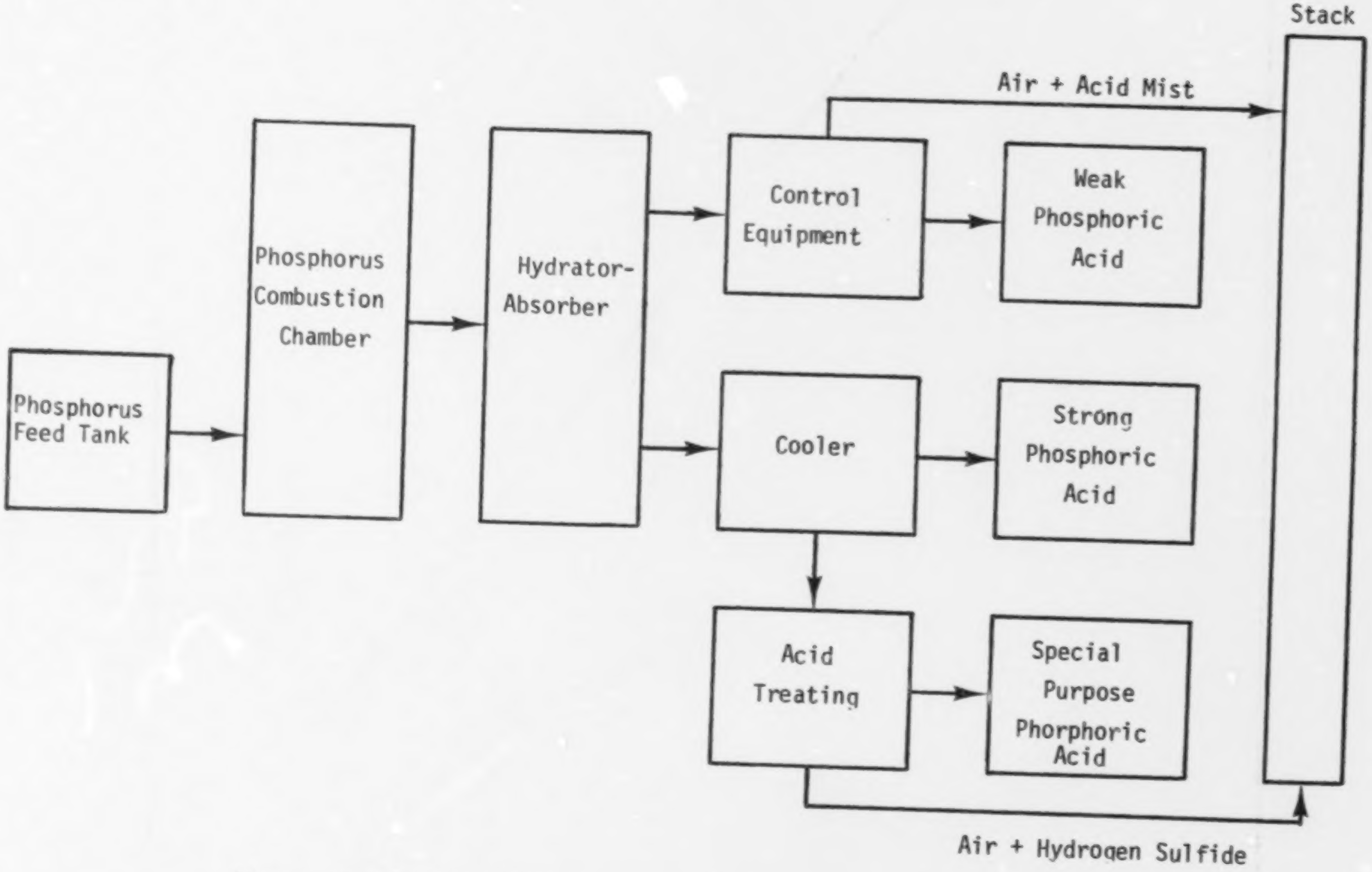

Stack
Air + Acid Mist
Phosphorus Feed Tank
Phosphorus Combustion Chamber
Hydrator-Absorber
Control Equipment
Weak Phosphoric Acid
Cooler
Strong Phosphoric Acid
Acid Treating
Special Purpose Phorphoric Acid
Air + Hydrogen Sulfide

Figure IV-8.3 Flow diagram for a typical thermal-process phosphoric acid plant

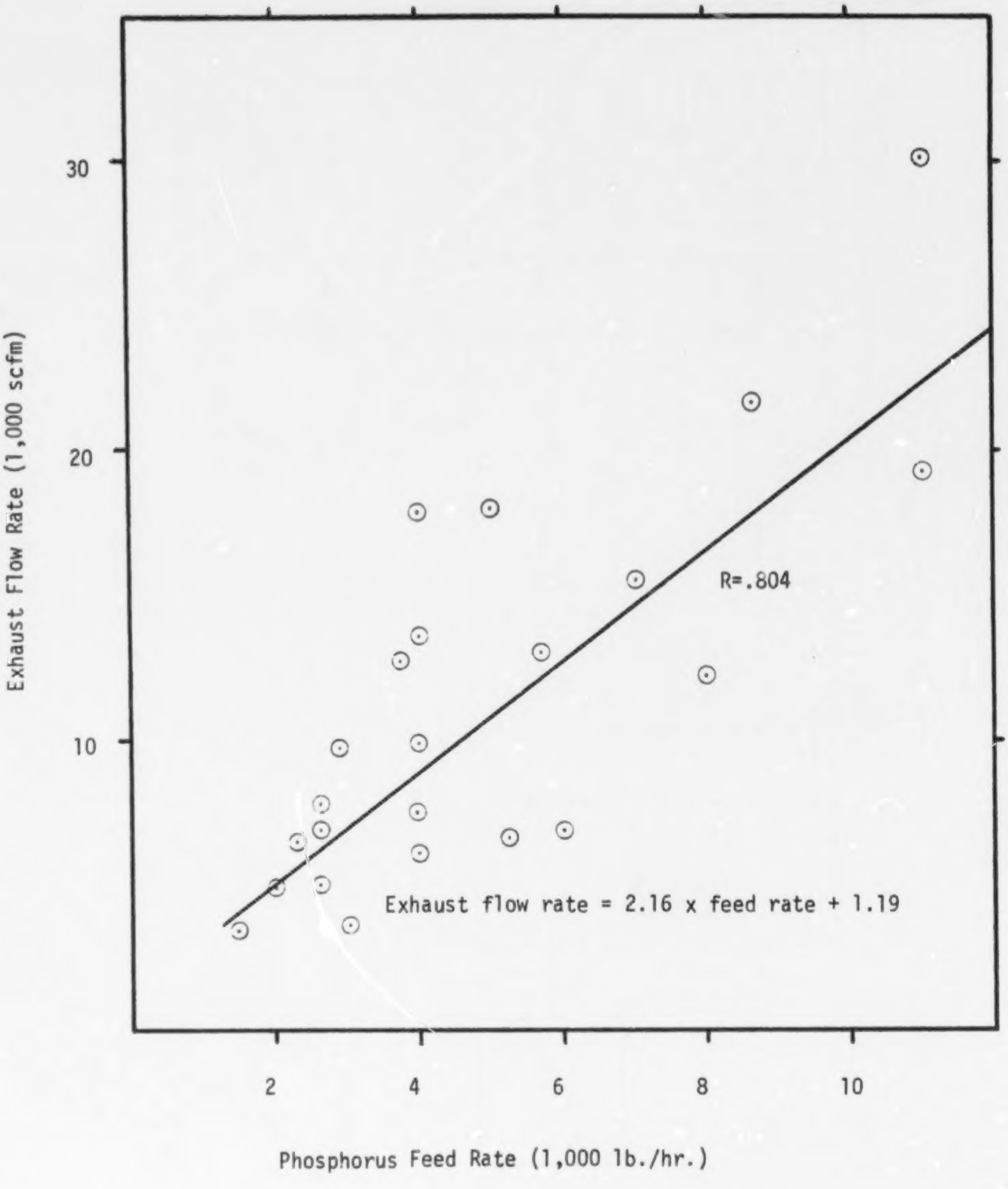


Figure IV-8.4 Exhaust flow rate vs. Feed rate for phosphoric acid thermal process

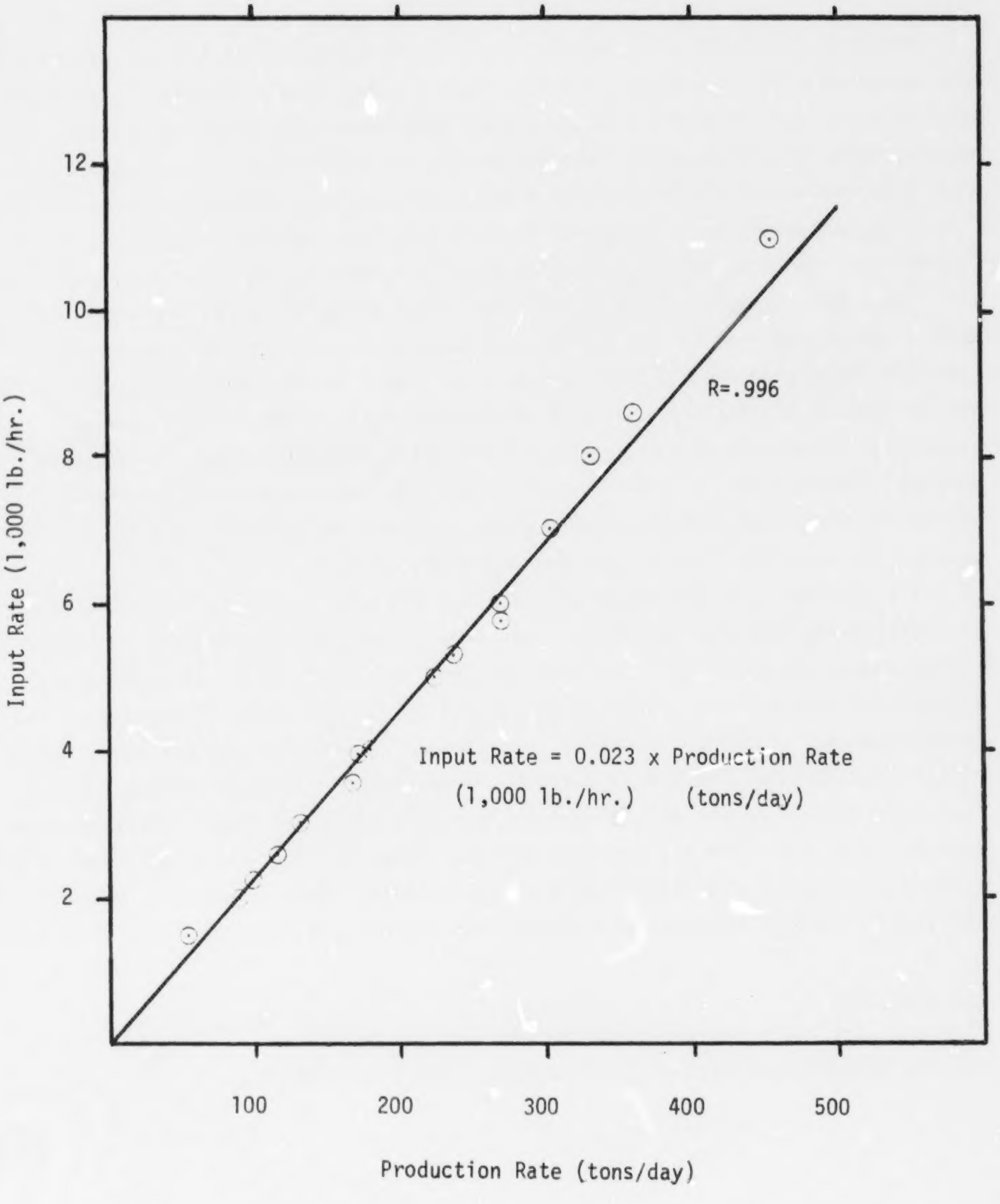


Figure IV-8.5 Input rates for the thermal process production of phosphoric acid.

CHAPTER IV-9

PHTHALIC ANHYDRIDE PLANT [A]

Phthalic anhydride was produced by twelve manufactures at sixteen plants in the continental U. S. and one in Puerto Rico in 1970 (Table IV-9.1). Annual production rates are about 1.2 billion pounds with individual plant capacities ranging from 30 million to 130 million pounds per year. Over ninety percent of U.S. phthalic anhydride is used for paints, plastics and synthetic resins.[21]

Phthalic anhydride is produced commercially from catalytic oxidation of naphthalene (or, more recently, o-xylene) with excess air in fixed or fluid bed converters. Figure IV-9.1 is the flow diagram for the fixed bed process. Only a few plants use the older fixed bed process since fluid bed processing has been demonstrated to be more economical. O-Xylene has slightly higher yields (pounds of phthalic anhydride per pound of raw material) with ranges from 70 to 95 percent while naphthalene has typical yield ranges from 70 to 85 percent (Figure IV-9.2). There are few operating variables in the phthalic anhydride plant thus variations from plant to plant are minimal. Plants operate continuously 3 shifts per day and 7 days a week.

The principal air pollution problem of a phthalic anhydride plant is off gas leaving the phthalic anhydride condensors. Major air contaminants include strong odors, phthalic anhydride (40-200 ppm), maleic anhydride (100-600 ppm), aldehydes (10-100) ppm and carbon monoxide (6,000 - 50,000 ppm).[21] Some fixed bed plants have air pollution scrubbers as a control measure for the off gas. Other plants use catalytic burners to oxidize contaminants.[22] Control system exhaust flow rate depends on the size of the process unit and plant size. Minor problems include fumes from beed and products storage tanks, venting during refining, flaking and bagging and leaks from the heat transfer fluid, Dowtherm. Whenever the minor points of emission are vented with the off gas, a larger unit is required.

GAS FLOW RATE

Gas flow rates for the fluid bed process are lower than fixed bed process and may be estimated with the aid of Table IV-9.2 and Figure IV-9.3.[17]

GAS TEMPERATURE

Exhaust gas temperatures from dry recovery condensors (commonly used with the fluid bed processes) range from 120 to 140°F. For the wet recovery systems (found with a fixed bed process) temperatures are 150 to 160°F. The wet recovery system is saturated with water and emits a large white plume as the moisture condenses in the stack and ambient air. For calculations, assume 140°F.

GAS VELOCITY

Gas exit velocity for plants having air pollution controls averaged 35 fps. Other plants had a stack exit velocity of 0.1 - 6.3 fps.

STACK HEIGHT

Stack heights for phthalic anhydride plants ranged from 12 to 110 feet with a mean of about 70 feet. Most plants not having any controls had stack heights of less than 30 feet.

TABLE IV-9.1

Phthalic anhydride manufacturers and locations

Manufacturer	Location
Allied Chemical Corp.	El Segundo, California
Allied Chemical Corp.	Ironton, Ohio
Allied Chemical Corp.	Philadelphia, Pennsylvania
BASF Corp.	So. Kearney, N. J.
W. R. Grace & Co. (Hatco)	Fords, N. J.
Koppers Company, Inc.	Bridgeville, Pa.
Koppers Company, Inc.	Chicago, Ill.
Monsanto Company	Texas City, Texas
Monsanto Company	Glouster Co., N. J.
Chevron Chemical Co. (Oronite)	Richmond, California
Hooker Chemical Corp.	Puerto Rico
Reichhold Chemicals, Inc.	Elizabeth, N. J.
Reichhold Chemicals, Inc.	Chicago, Ill.
The Sherwin-Williams C.	Chicago, Illinois
Stephan Chemical Company	Millsdale, Illinois
Union Carbide Corp.	Institute, W. Va.
United States Steel Corp.	Neville Island, Pa.

TABLE IV-9.2

Exhaust Gases from Phthalic Anhydride Plants[17]

Process Step	Input Rate 1000 lb.	Exhaust Flow cfm	Exhaust Temp. °F.	Exit Velocity fps	Stack Height ft	Operating Time	Control
Reactor	16.0/hr.	116,200	90	34.2	110		Wet scrubber
	2.8/hr.	32,600	400	43.0	82		Catalytic incinerator
	25.0/hr.	50	85	35.8	30		
Condensors							
3	50.0/bat	67	120	5.5	44	½ hr/bat, 10 bat/day	
1	50.0/bat	34	70	6.25	44	½ hr/bat, 10 bat/day	
1	40.0/bat	--	75	0.7	30		
Storage	393/bat	20	Ambient	5.5	36.5	6½ hrs/bat, 2 1/3 bat/wk	None
	220/bat	20	174	5.5	45.8	4 hrs/bat, 1 bat/day	None
2 ea	220/bat	2.2	174	0.6	23.8	24 hrs/bat 3.5 bat/wk	None
	165.3/bat	900	156	4.8	12		Scrubber
Treater (2 ea)	70.0/bat	20 scfm	70	0.1	30		
Refining		444	120	1.2	12		

TABLE IV-9.2

Exhaust Gases from Phthalic Anhydride Plants (cont'd)

Process Step	Input Rate 1000 lb.	Exhaust Flow cfm	Exhaust Temp. °F.	Exit Velocity fps	Stack Height ft.	Operating Time	Control
Drying	43.3 lb/bat	37.2	180	3.2	70	20 min/bat 3.5 bat/wk	None
	6900 lb/bat	37.8	180	3.2	70	½ hr/bat, 3.5 bat/wk	

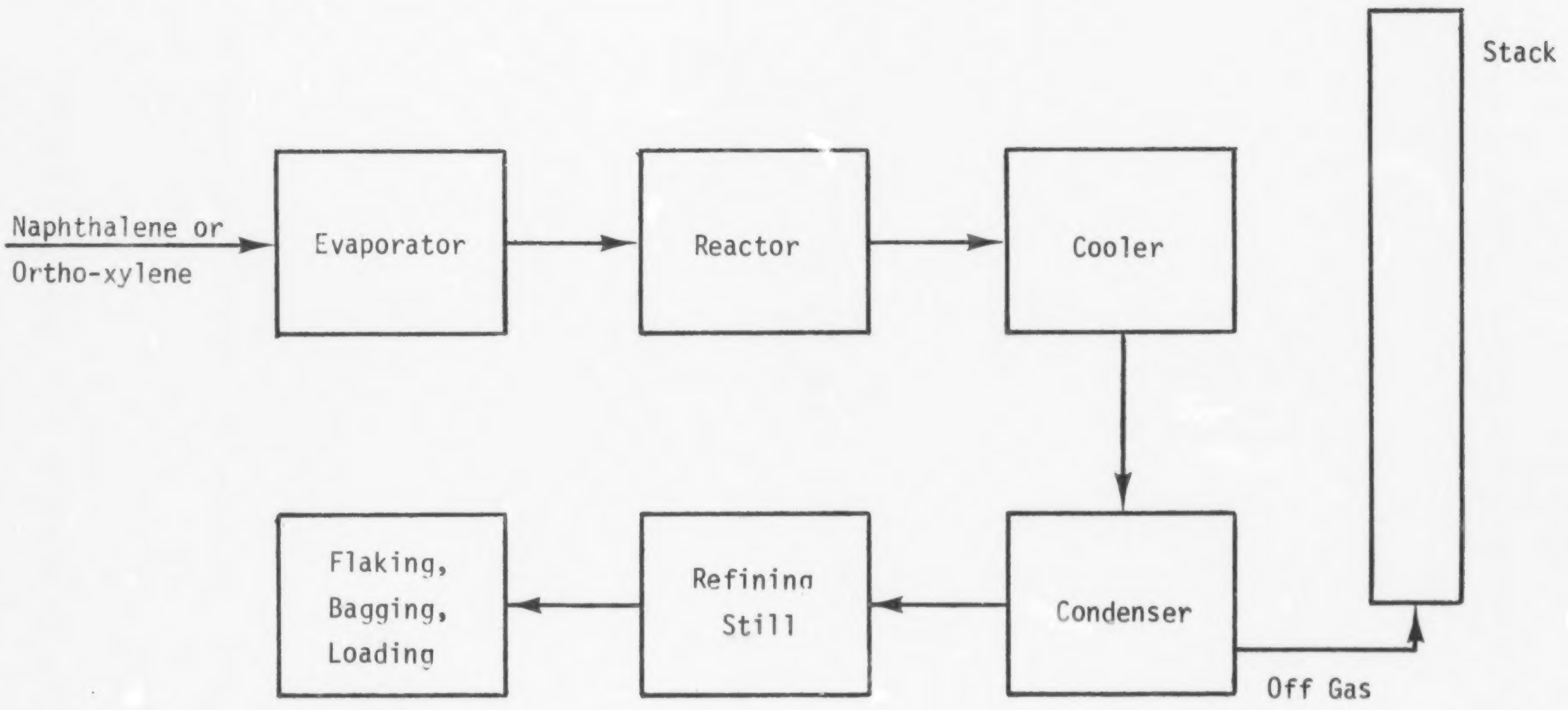

Naphthalene or
Ortho-xylene
Evaporator
Reactor
Cooler
Stack
Condenser
Off Gas
Refining
Still
Flaking,
Bagging,
Loading

Figure IV-9.1 Flow diagram of the fixed bed process for phthatic anhydride production

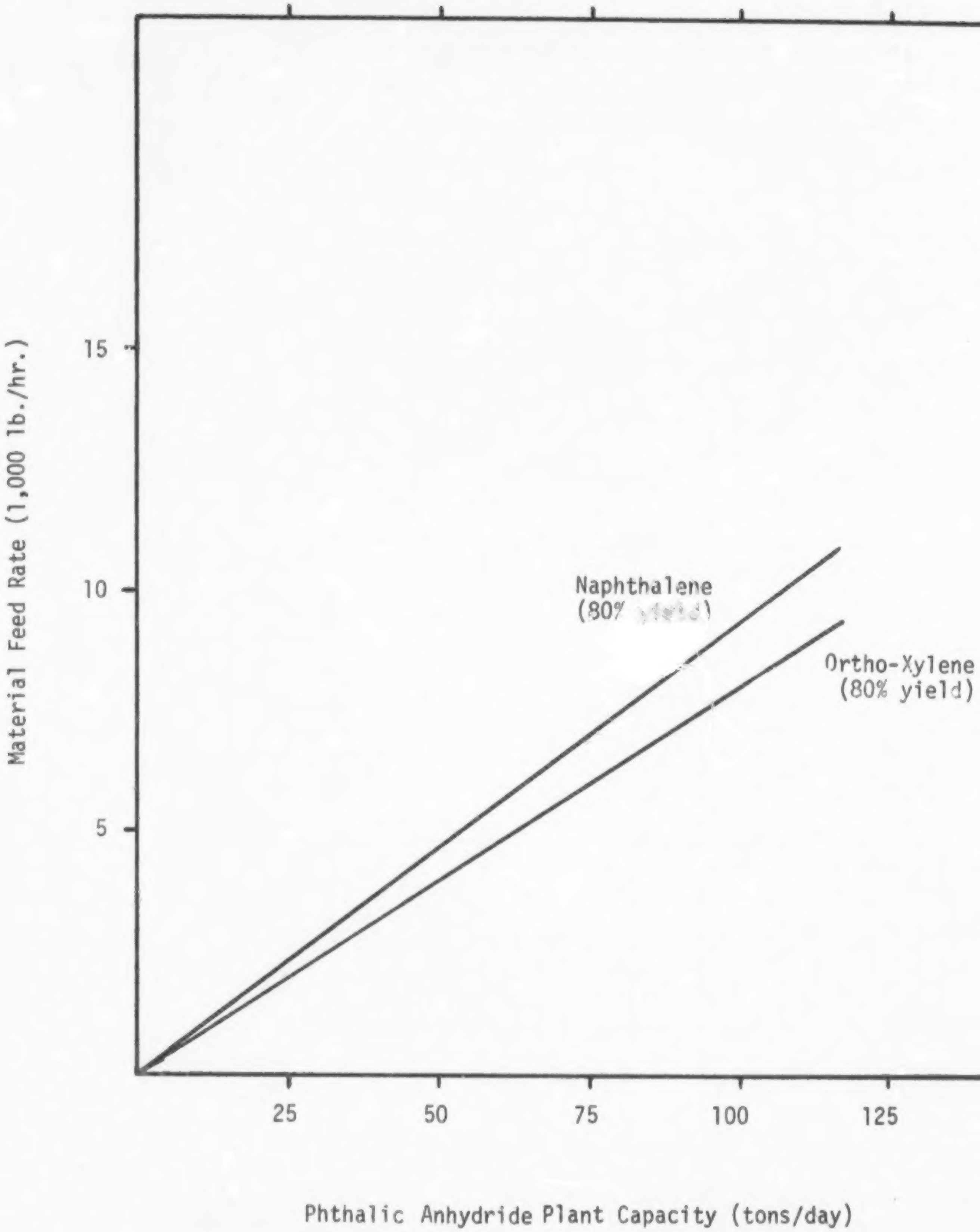


Figure IV-9.2 Plant capacity vs. feed rate for Phthalic Anhydride production

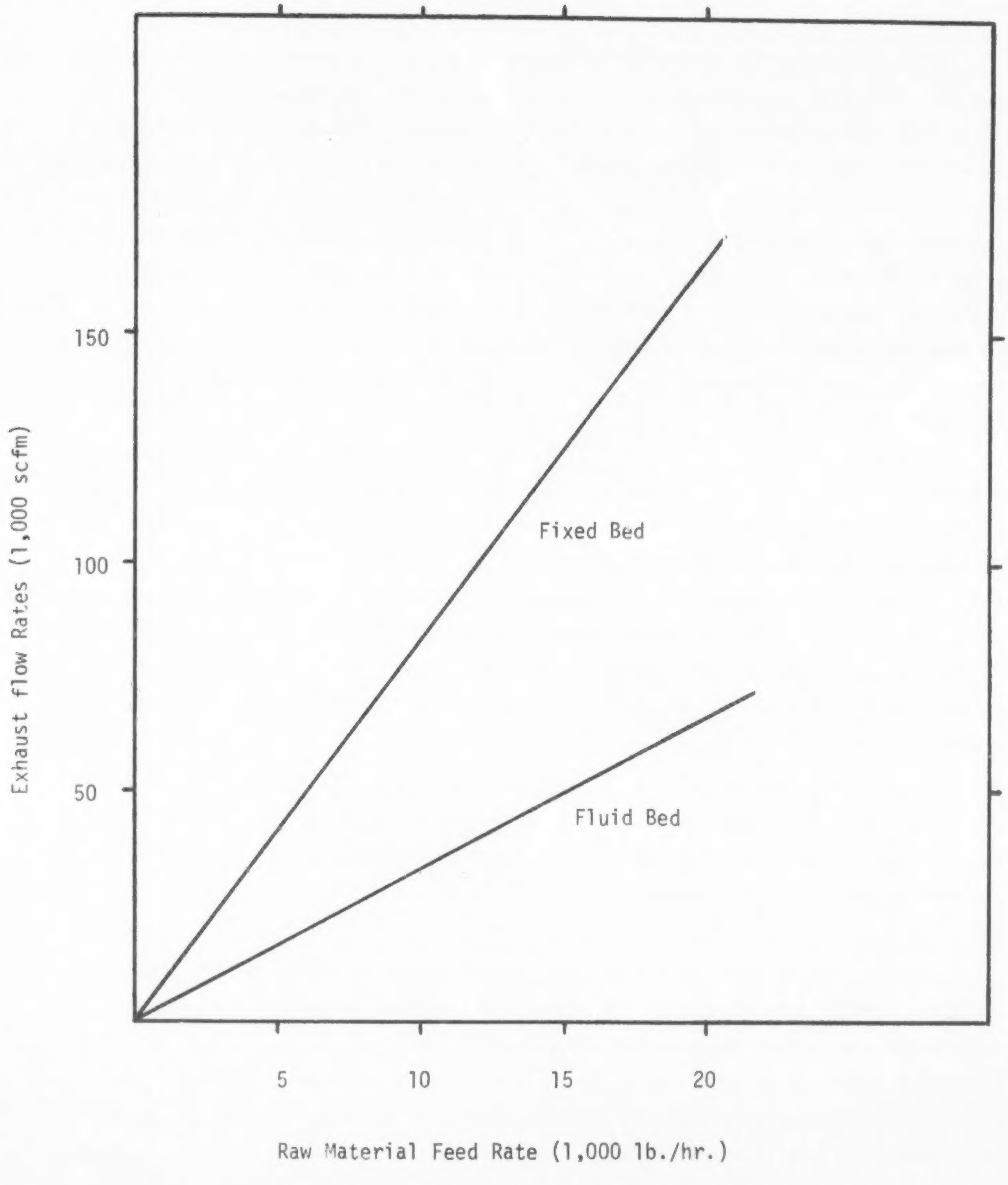


Figure IV-9.3 Exhaust flow rates for various feed rates in production of Phthalic Anhydride

CHAPTER IV-10

PLASTICS PLANT [B]

The manufacture of synthetic resins or plastics is mainly a polymerization process. Various raw materials, gas and liquid, are processed to provide long chain-like molecules which are the pith of plastic production. The 1964 annual production rate was 10 billion pounds. As in the case with other polymerization type industries, there are a large number of finished products (plastics) which are made from a variety of raw materials. By varying monomers, different products are manufactured. Raw materials used in manufacturing plastics include formaldehyde, phenol, phthalic anhydride, butadiene, ethylene, propylene and styrene. Processing is entirely closed within stainless steel vessels and transport lines. Most plants run continuously for 24 hours per day and 7 days a week with virtually no shut down.

Plastic plants may or may not generate air contaminants.[23] In all cases, emissions will be highly variable. For example, holding tanks for the monomers or other input materials often are vented to the atmosphere, but, depending on volatility and vapor pressure, little or no hydrocarbons may be discharged unless the tank is filled. Likewise, holding or weighing tanks will only produce emissions when being filled. The reactors themselves will generate a continuous small volume of hydrocarbons during polymerization. The only control equipment would be catalytic afterburners in the size range of 2-10,000 scfm for combinations of vents or reactor exhausts.

Typical process weights from various plants run from 800 to 40,000 lb./hr. (Table IV-10.1)[17]. Plant capacity is determined by the number of polymerization units. When more production capacity is needed, another "line" or series of polymerization units are added.

GAS FLOW RATE

Based on available data from five plants, exhaust flows ranged from 50 to 8,000 scfm (Table IV-10.1). Figure IV-10.1 provides a display of the data which shows that no apparent relationship exists between exhaust flow and process weight. Some flow rates (it is not known which ones) probably vent an entire area including the polymerization vessel while others represent only the off gases from one reactor vessel. For modeling purposes, the exhaust flow of the control device/stack should be used, if known. When no information is available use 5,000 scfm for the total plant.

GAS TEMPERATURE

Gas temperatures for the plants available ranged from ambient to 1400°F. However, 10 of the 11 data points were 150°F or lower. It is speculated that the one plant which exited flue gases at 1400°F probably had an afterburner in operation. A mean temperature of 100°F can be assumed when no control equipment is used.

GAS VELOCITY

A stack velocity of 35 fps should be used for modeling. The range was from 1 to 67 fps. It is apparent from the data that velocity is independent of the size of the operation but depends on the particular plastic being produced or design of the process equipment itself.

STACK HEIGHT

Table IV-10.1 shows vent and reactor stacks to range in height from 8 to 105 feet, with about 60 feet being the mean.

TABLE IV-10.1

Exhaust Gases from Plastics Plants[17]

Input Rate 1000 lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity 1000 fps	Stack Height ft.
0.8	7.98	1400	120.0	8
40.0	1.20	Ambient	36.0	91
40.0	0.74	150	255.0	10
1.2	0.05	Ambient	36.0	80
1.5	0.50	Ambient	120.0	40
5.0	2.74	120	138.0	103
1.5	6.00	Ambient	123.6	40
31.2	4.78	150	150.0	105
5.0	0.54	Ambient	394.8	32
1.0	0.45	125	147.0	40
2.5	1.70	70	3.0	98
11.8	3.43	211	138.5	58.8

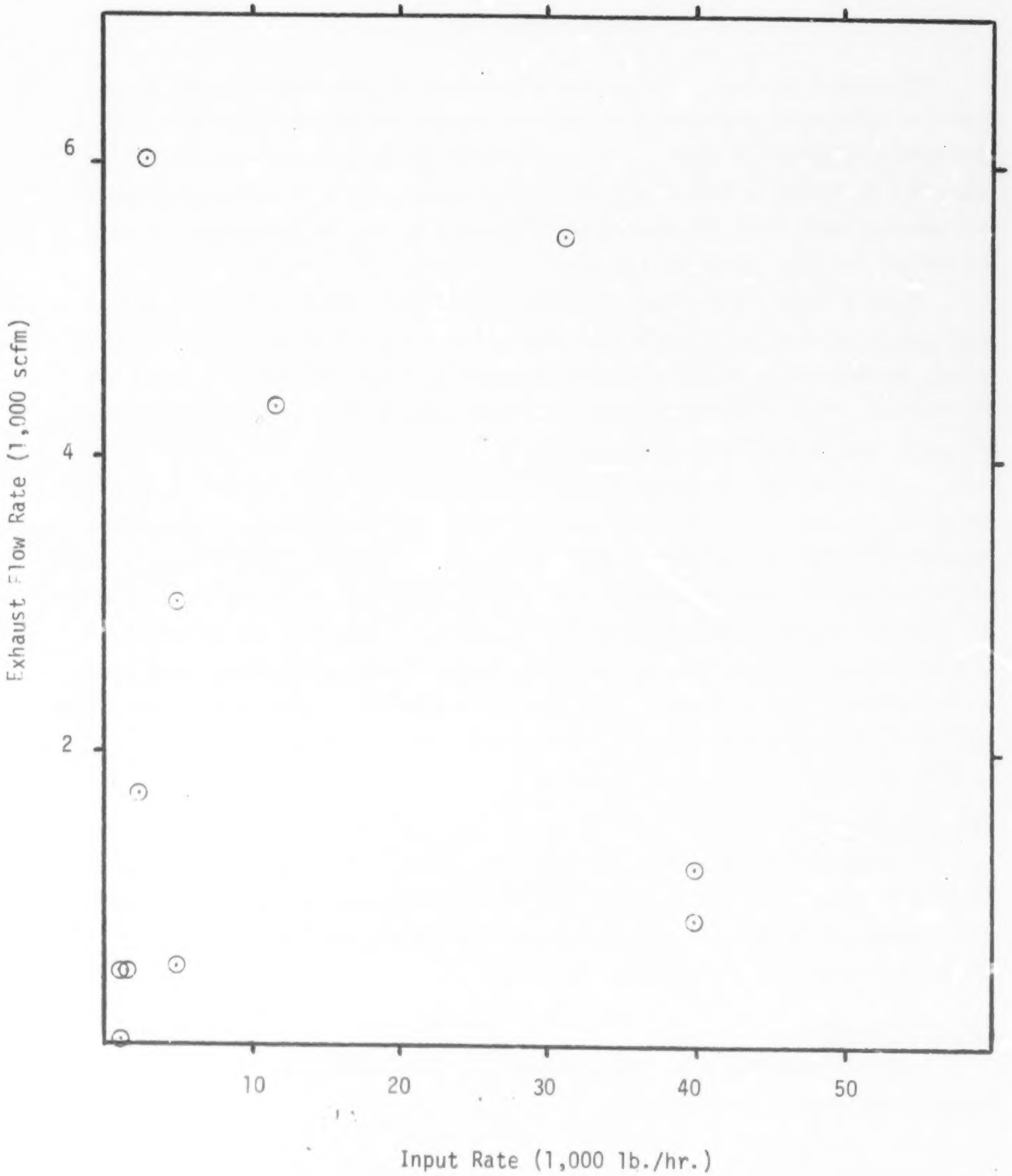


Figure IV-10.1 Exhaust flow rate vs. process weight for plastic plants

CHAPTER IV-11

PRINTING INK PLANT [E]

Printing inks consist of a fine dispersion of pigments or dyes in a vehicle which may be drying oils with or without natural or synthetic resins and added driers or thiners. The composition of printing inks varies as to specific application or end use, with some containing a higher percentage of driers (as those used for newspaper ink), while others contain high percentages of resins for high gloss applications.

There are two basic types of inks; 80 percent of the ink is of an oil type which is used for offset and letter press and 20 percent is of a solvent type which is used for flexographic and gravure operations. There are about 500 - 600 ink manufacturers scattered through the U. S., and they manufacture about 1 billion pounds per year.

The manufacture of printing ink is a mixing operation which is carried out in steel tubs.[24] Most all manufacturers buy the base resins from paint suppliers. There is no heat associated with the process. The principle air pollutant is dry color pigments. All plants will control pigment particulates with either portable or permanent scrubbers (and baghouses) to prevent contamination of other inks. The solvent type inks are mixed in tanks and are in an entirely closed system.[24] Few plants have solvent vapor control equipment. Plants typically operate 1 or 2 shifts a day for 5 to 6 days a week.

GAS FLOW RATE

No data were available to analyze flow rates. It is estimated that between 2,000 and 10,000 scfm are used to control pigment dusts from each tub during the loading of the raw pigment into the tubs.[24] For solvent type operations there is no flow rate.

GAS TEMPERATURE

Since no combustion is taking place within the process, the gas exit temperature will be ambient.

GAS VELOCITY

No specific data were obtained. The exit velocity from controlled plants is about 20 - 40 fps.

STACK HEIGHT

Stack heights are expected to be about 30 feet since most plants are one story buildings.

CHAPTER IV-12

SOAP AND DETERGENTS PLANT C

"Detergents"

The use of detergents as a cleansing agent for domestic and industrial use has risen rapidly since 1945 to an annual production of about 3 million pounds.

Synthetic detergents are manufactured continuously from a number of surfactant materials, builders and additives. A typical example of the raw materials follows for producing 1000 lbs. of finished product:

Ingredient	Pounds
Surfactant materials	
Alkylbenzene	75
Fatty Alcohol	75
Oleum	150
NaOH solution	200
Corrosive inhibitor	
Sodium silicate	125
Builder	
Sodium tripolyphosphate	500
Miscellaneous additives	30
Water	500

The raw materials are mixed and passed through a crusher to a drop tank. The wet slurry is then spray dried in a vertical countercurrent tower with the dried detergent leaving at the bottom and exhaust gases exiting the top (Figure IV-12.1).

The ratios of the various raw materials will depend upon which end use is sought. However, no simple relationship exists between input and output.

The major source of emission is the spray drying tower (Figure IV-12.1).[25] The drying normally occurs in large towers 20 feet in diameter and about 100 feet high. Cyclones are used to remove the detergent particles from the conveying air stream and these fines are returned to the process. Additional controls such as spray chambers, packed scrubbers or venturi scrubbers may follow the cyclone.

GAS FLOW RATE

From available data drying tower flow rates ranged from 14,000 to 66,000 scfm.[17] However, concurrent production data were not available for this one plant. Where specific information is unknown 40,000 scfm may be assumed.

GAS TEMPERATURE

Temperature of gases from the spray dryer is relatively constant ranging from 120 to 129°F for all types of detergents. Where data is unavailable 120°F should be used. Exit temperatures from handling and airveying operations would be ambient.

GAS VELOCITY

Gas velocity from six drier stacks ranged from 33 to 156 fps with about 100 fps the average velocity. Data from one plant showed stack diameters of 3 feet.

STACK HEIGHT

Stacks from the drier are generally located on the roof of the manufacturing plant and extend above roof line. Since the drying towers are 100 or so feet in height, stack height can be expected to range from 100 to 125 feet with 125 feet about average. However, the data from one plant with five driers showed stack heights of 15.5 to 45 feet; it is speculated that these heights are above the roof. For calculations assume at least 50 feet for stack height.

"Soap"

Soap is manufactured on a large scale with most plants having a capacity of about 300 tons/day. Tallow is the principal material used in soap making. Soap plants are scattered about the country since the raw materials are abundant.

The soap making process is simple: raw materials are heated, mixed with chemical additives, then chilled, dried and pressed into bars. The principal air pollution problem from a soap plant is odors. Originally, odors from the centrifuge room were exhausted directly to the atmosphere, but today most soap plants have control equipment installed. Some plants reportedly use venturi scrubbers to attain an odor elimination efficiency of up to 90 percent.[26] Catalytic oxidizers also are used to control odors.

GAS FLOW RATE

No data were available, but, since the size of the air pollution control device is dependent on the volume of the room or plant being ventilated, most plants would keep the volume to a minimum to increase efficiencies and decrease costs. It is suggested that 5,000 scfm be used in estimates.

GAS TEMPERATURE

No data were available but for all practical purposes, the gas temperatures would have to be ambient since room ventilation air is being exhausted. Therefore, use 60° in calculations.

GAS VELOCITY

No data were available but maximum velocities above 50 fps would not likely be exceeded due to increased friction losses.

STACK HEIGHT

No data were available but assuming soap and detergent would be manufactured in the same plant, stack heights certainly would not exceed detergent drier stacks and most likely would be less than 50 feet high. Table IV-12.1 provides information for both detergents and soap.

TABLE IV-12.1

Exhaust Gases from Soap and Detergent Plants[17]

Input Rate	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameter ft.	Operation Time
DETERGENTS						
	48.8	129	115	15.5	3.1	
	48.8	129	115	15.5		
	14.0	127	33	15.5		
	66.0	127	156	15.5		
	60.0	124	142	15.5	3.1	
100,000 lb./hr.	14.5	120	65	45		
SOAP						
8,000 lb./batch	50.0	70		26		16 batches/day, 30 min./bat.

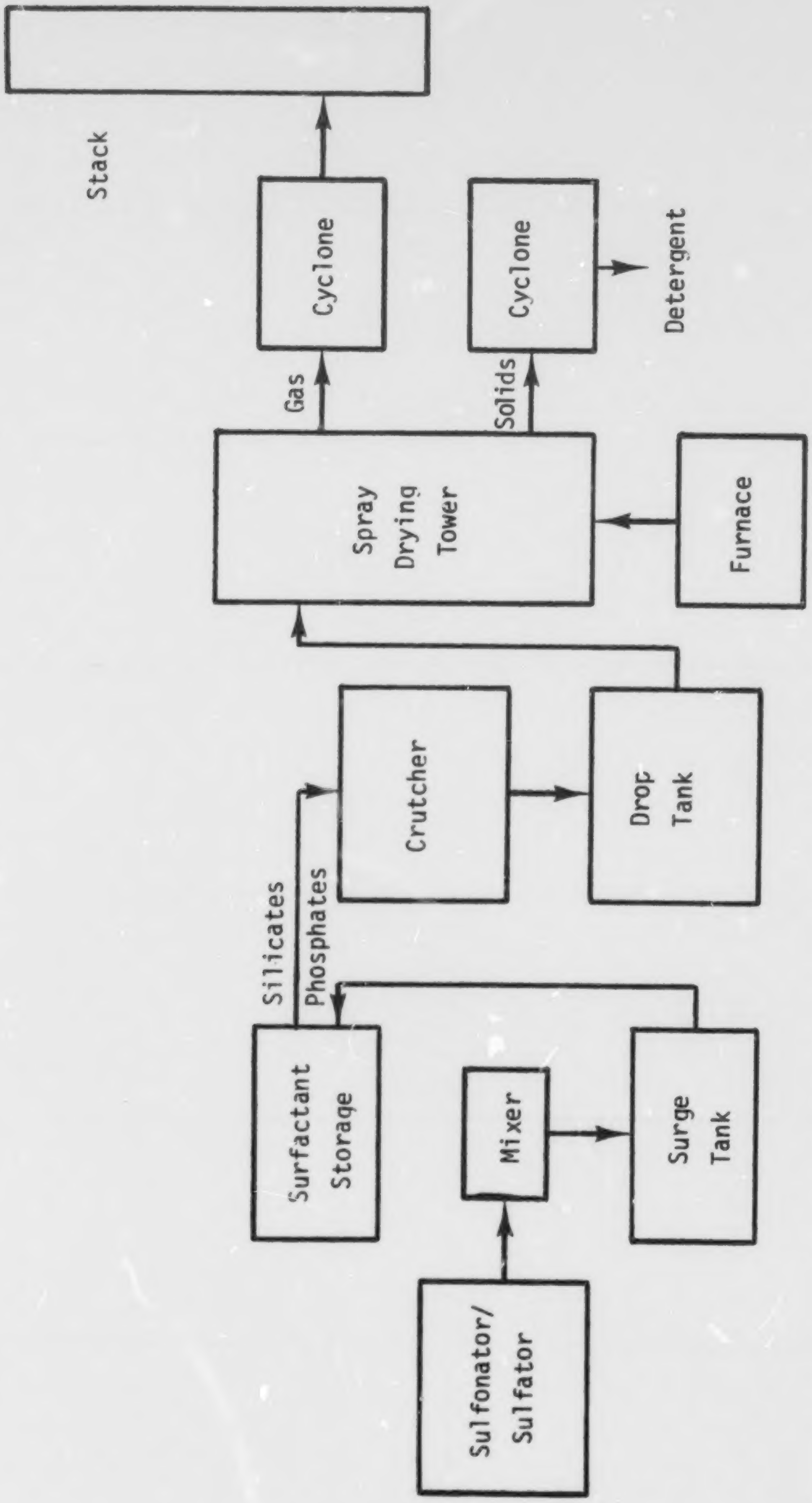

Sulfonator/
Sulfator
Mixer
Surge
Tank
Surfactant
Storage
Silicates
Phosphates
Crutcher
Drop
Tank
Spray
Drying
Tower
Furnace
Gas
Solids
Cyclone
Cyclone
Detergent
Stack

Figure IV-12.1 Flow diagram for a detergent plant

CHAPTER IV-13

SULFURIC ACID PLANT [A]

Sulfuric acid is largely used as a raw material in an extremely wide range of industrial process and manufacturing operations with one-third of it being used for the production of phosphate fertilizer. Sulfuric acid plants are scattered throughout the U.S. There are about 215 contact H_2SO_4 plants which account for 90 percent of the 20,500,000 tons produced annually. The remaining 10 percent is produced by the older lead chamber process. The chamber process is tending to become a very small factor in sulfuric acid manufacture because of the weak solution and initial construction costs. Chamber plants in general are captive, are of low capacity, and are considered a small air pollution potential for the U.S.

The yellow sulfur mineral itself (appearing mainly in the molten state) accounts for about 75 percent of the raw material used for sulfuric acid production. In either the contact or chamber process one pound of raw sulfur is needed to make 3 pounds of sulfuric acid (100 percent concentration).[27]

$$1 \text{ ton/day raw sulfur input} = 3 \text{ ton/day } H_2SO_4 \text{ output} \qquad \text{IV-13.1}$$

The major source of emission from the contact sulfuric acid plant is the exit gas from the absorber. Minor amounts of sulfur oxides may be emitted to the atmosphere from tank car and drum loading operations and from storage tank vents. Other pollutants like nitrogen oxides may be emitted from the process acid tanks in the chamber process.

Sulfuric acid plants usually have no air pollution control devices per se. The absorber could be considered as an air pollution device since its function is to absorb the SO_2 gases produced earlier in the processes. The greater the absorption efficiency, the less SO_2 emissions will result. Thus, it is the efficiency of the absorbtion system which determines the emission factors. Single and two stage absorber systems reduce SO_2 concentrations in tail gases to 1000-5000 ppm and 500 ppm, respectively.[28] Further reduction may be obtained with wet scrubbing units using soda ash, sodium sulfite, bisulfite and plain water. Electrostatic precipitators may also be used in conjunction with the wet purification systems. These devices do not change flue gas flow rates but may produce a temperature drop. Tables IV-13.1 and IV-13.2 list operational for plants with and without mist elimination.

GAS FLOW RATE

Figures IV-13.1 and 13.2 indicate that the exhaust gas flow rate is a near linear function of the daily production rate. There does not seem to be a significant difference whether solid or molten dark raw sulfur is used or whether air dilutation or no air dilution is used and only a small difference whether or not mist eliminators are used. Thus, by knowing only the production rate of sulfuric acid the exhaust flow rate can be determined accurately.

GAS TEMPERATURE

There does not seem to be a general relationship about flue gas temperatures. Based on the collected data the temperatures ranged from 76 to 212°F with an average of about 160°F. No conclusions could be made regarding the effect on temperature of mist eliminators, type processes, molten or solid raw sulfur or plant efficiency.

GAS VELOCITY

Of the 6 plants where gas velocity data were available, the velocity ranged from 775 to 2,820 fpm with an average of near 1,800 fpm or 30 fps.

STACK HEIGHT

The stacks from sulfuric acid plants mostly range from 100 to 200 feet in height and are about 2 to 3 feet in diameter. The stacks are usually metal and for some reason painted with red and white stripes. Where such data are unavailable 150 feet should be used.

TABLE IV-13.1

Exhaust Gases from Sulfuric Acid Plants Without Mist Eliminators[27]

Production Rate tons/day	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Conversion (%)
735	48	212	97.8
650	52	175	96.0
650	52	175	96.0
120	8.2	115	97.5
422	27.0	123	97.5
130	8.0	175	97.2
100	7	173	97.8
100	7	168	97.8
325	18.0	148	95.7
325	17.9	148	95.6
162	11.8	140	98.5
115	6.4	94	98.1
210	12.9	-	97.7
500	32.3	170	96.7
310	18.3	105	97.6
265	15.0	170	96.5
285	21.1	190	97.5
650	63.0	136	96.3
302	21.2	163	98.7
900	66.8	145	97.8

TABLE IV-13.2

Exhaust Gases from Sulfuric Acid Plants With Mist Eliminators [27]

Production Rate tons/day	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Stack Velocity fps	Conversion (%)
961	62	186		98.5
150	8.0	165		97.6
150	8.0	166		97.5
240	-	180		
240	-	180		97.2
219	13.0	76		98.2
133	8	76		98.2
300	18	175		96.9
265	15	160		98.0
300	23	180		97.8
429	30.2	176		98.0
272	20.8	150		96.7
429	30.2	176	33.2	98.0
422	27.0	123	27.0	97.5
272	20.8	150	18.0	97.6
302	21.2	163	12.9	97.8

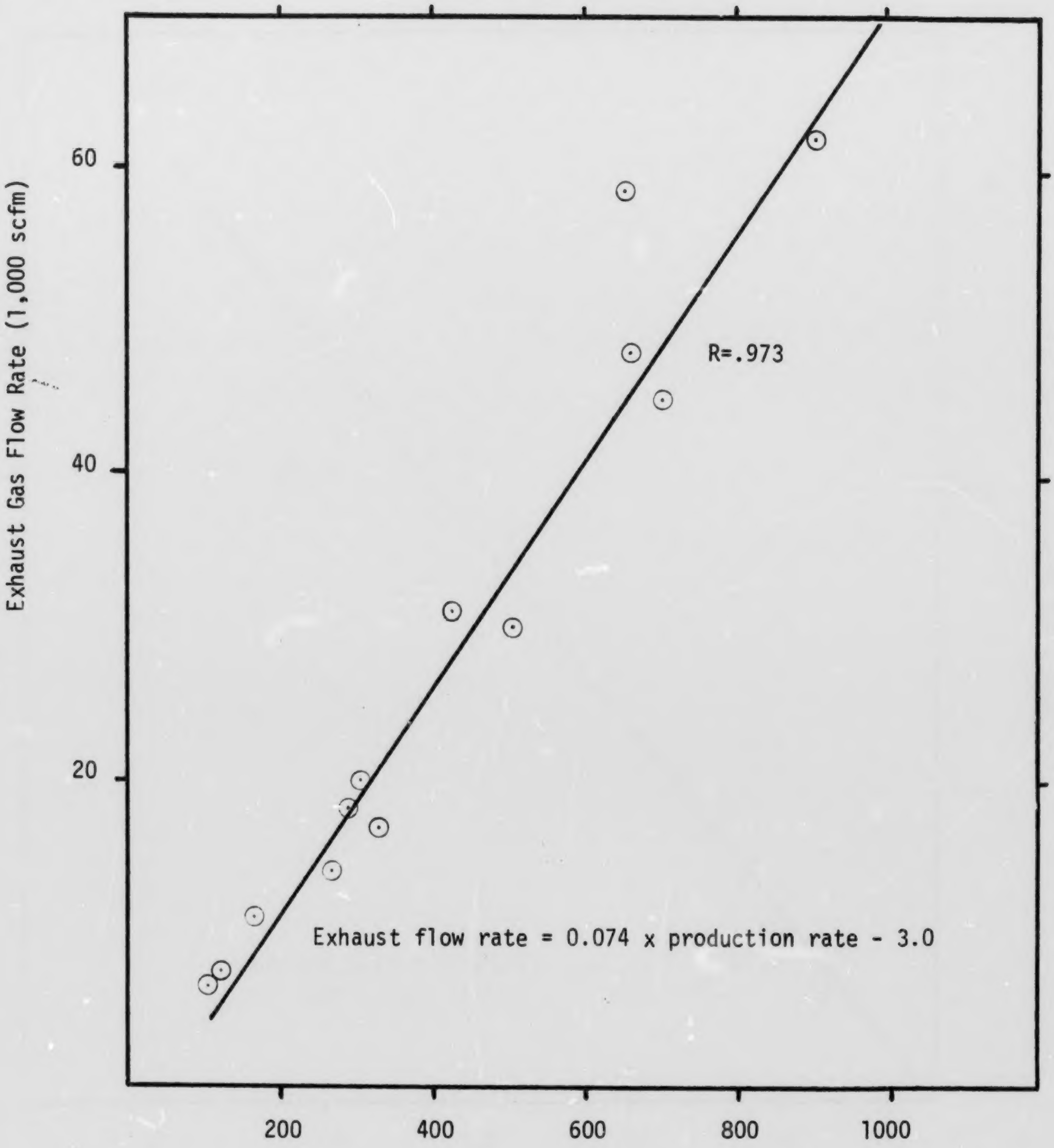


Figure IV-13.1 Exhaust gas flow rate as a function of production rates for the sulfuric acid contact process without mist eliminators.

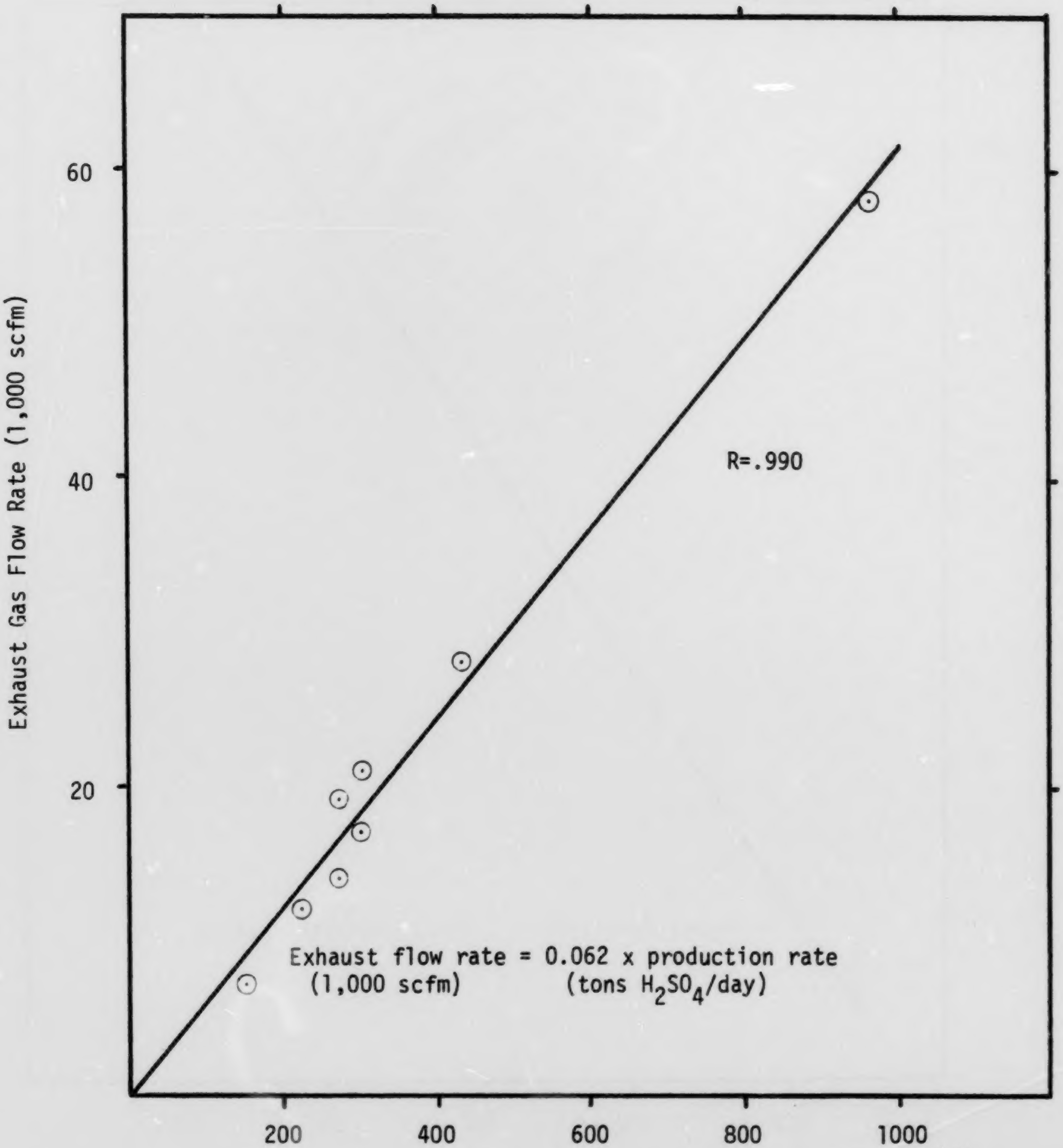


Figure IV-13.2 Exhaust gas flow rate as a function of production rates for the sulfuric acid contact process with mist eliminators.

CHAPTER IV-14

SYNTHETIC FIBERS PLANT [D]

Synthetic fiber production includes nylon, orlon, dacron, rayon and acrylic, although nylon alone constitutes about 25 percent of the total synthetic fiber production in the U. S. The annual production rate of non-cellulosics (true synthetic) fibers was about 1.2 billion pounds in 1965 processed from about 25 plants scattered around the U. S. Typical plant size is about 50 - 150 million pounds per year.

Basic raw materials for non-cellulosic fibers are mainly carbon-hydrogen chains originating from natural gas and petroleum fractions. The flow diagram for a synthetic fiber manufacturing process is shown in Figure IV-14.1. Ingredients used in the manufacture of three synthetic fibers include: [16]

nylon 66 - adipic acid, hexamethylene diamine
dacron - dimethyl terephthalate and ethylene glycol
acrylon and orlon - acroylonitrile

The chemical manufacturing process is almost entirely an enclosed system and no by-products are formed; thus, for every pound of raw materials used the yield is a pound of fiber. Large nylon plants are located in Seaford, Delaware; Martinsville and Richmond, Virginia; and Chattanooga, Tennessee.[16] The plants operate continuously 24 hours a day and 365 days a year.

The polymerization process is a batch process. Each autoclave reactor or blender has a capacity of about 1 ton. Plant capacity, however, depends primarily on the number of evaporators available. Potential air pollution problems are mainly attributed to the evaporators where water vapor and hydrocarbons are emitted. The evaporators are under pressure and "trickle off" during this phase. Usually a small 2" vent pipe is used. At the end of this phase the evaporator is vented directly to the atmosphere.[29]

Very few synthetic fiber plants use any air pollution control devices to abate process emissions. One nylon plant has just begun to abate emissions from the evaporator and uses catalytic oxidizers. Heat requirements of the units are not by direct flame but by indirect heating with the process heat fluid Dowtherm.

GAS FLOW RATE

Based on observations of the evaporator operation, it is estimated that about 200 scf of exhaust gas is emitted in 5 seconds. The complete cycle on the evaporator is about 2 hours.

GAS VELOCITY

Exit velocity, based on observations of the operation, indicate intermittent (every 2 hours) velocities of about 200 fps. No data were available.

GAS TEMPERATURE

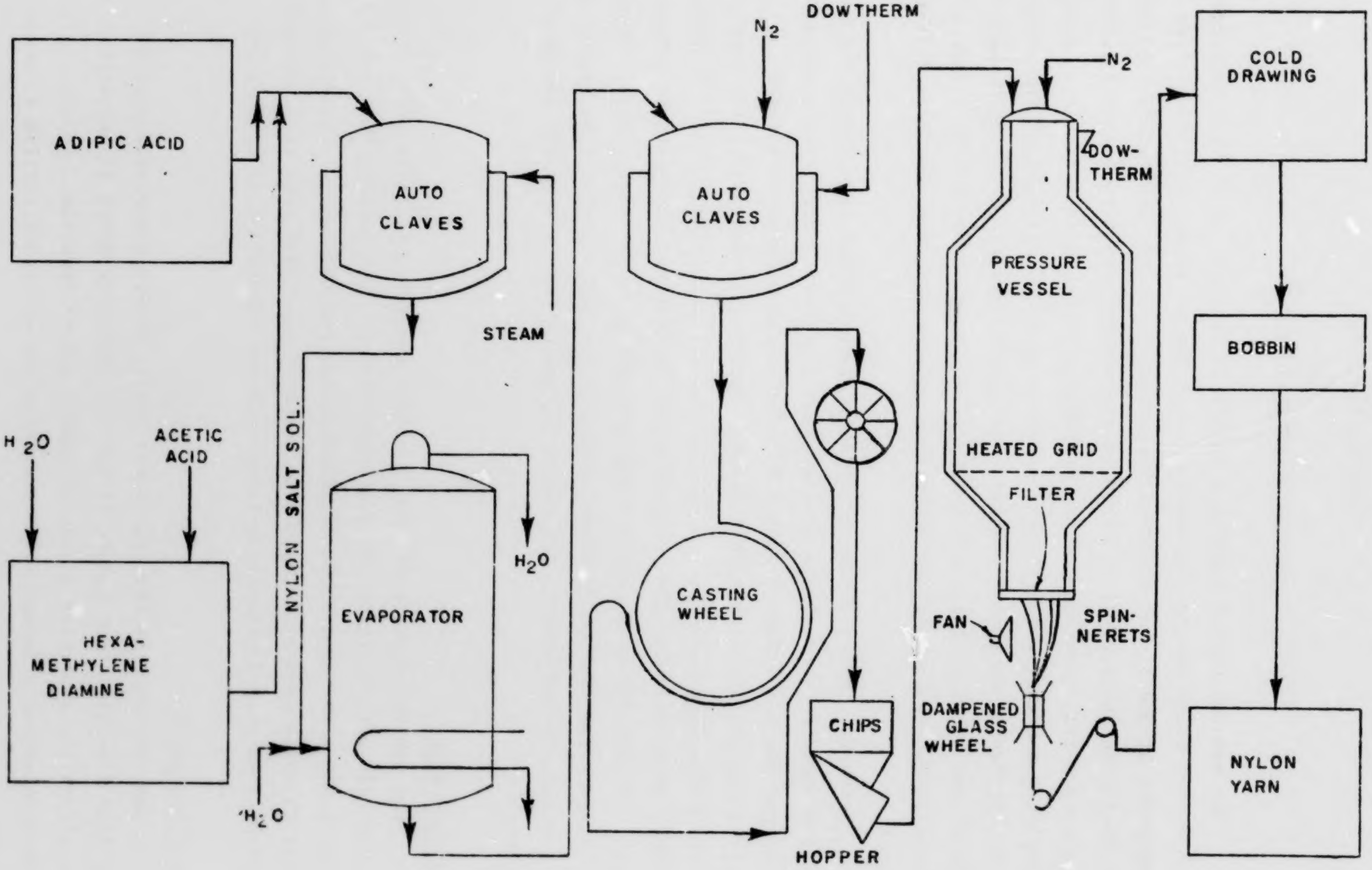
Stack gas temperatures are estimated to be 500°F although no data were available.

STACK HEIGHT

Stacks from the evaporators are 6" diameter pipe extending through the roof of the plant about 4 feet. Every evaporator will have a stack. When no other information is available, a stack height of 75 feet should be used.

FIGURE IV-14.1

FLOWCHART FOR NYLON YARN PROCESS


ADIPIC ACID
H $_2$O
ACETIC ACID
HEXA-METHYLENE DIAMINE
NYLON SALT SOL.
AUTO CLAVES
STEAM
EVAPORATOR
H $_2$O
H $_2$O
N $_2$
DOWTHERM
AUTO CLAVES
CASTING WHEEL
CHIPS
HOPPER
N $_2$
DOW-THERM
PRESSURE VESSEL
HEATED GRID
FILTER
FAN
SPIN-NERETS
DAMPENED GLASS WHEEL
COLD DRAWING
BOBBIN
NYLON YARN

CHAPTER IV-15

SYNTHETIC RUBBER PLANT [B]

The manufacture of synthetic rubber is carried out by many processes with each rubber class having various ratios of raw materials utilized. Some of the commercial monomers, the intermediate material for synthetic rubber production, are listed in Table IV-15.1. Each of the monomers requires extremely different feed ratios from a variety of raw ingredients like butane, ethylene, propylene, acetylene, benzene, carbon black, sulfuric acid and oil. Tires for example may have 5 different synthetic rubbers used in the same tire; casing rubber, inner wall of the tubeless tire, ply build-up rubber and tread rubber.[16] Each of these synthetic rubbers originates from different processes and sometimes different plants.

Synthetic rubber plants are scattered throughout the country and have a total production rate of 2.2 million long tons/year. Most plants operate 24 hours per day and 7 days a week like other chemical process industries. In general, the process is entirely closed with just a few points for venting off gases. Data from three New Jersey plants, all producing the same kind of tire rubber, indicated that the polymerization process had the greatest exhaust flow rates. Pollutants of importance are hydrocarbons and particulates. Controls for hydrocarbon are incinerators; controls for particulates from mixing and ball mills are scrubbers. The extent of use of controls in the industry is unknown.

GAS FLOW RATE

The exhaust flow rates from 3 plants are shown in Table IV-15.2 and may be considered typical for one kind of tire rubber.[17] The exhaust flow rates averaged about 1,800 scfm for a 5,600 lb./batch polymerization unit. Fluidizing polyvinyl chloride powder in 200,000 lb. batches also gave rise to 1,600 scfm. The vent on a polyvinyl chloride holding tank was exhausting at 2,850 scfm.

GAS TEMPERATURE

Gas temperatures from the three plants showed temperatures of 60 - 100°F. The data from the three plants is not all inclusive since it represents only a few plants and processes of the synthetic rubber spectrum. However, discussions with knowledgeable industrial representatives and stack testing at other polymerization plants suggests that most exhaust stack gases will be near ambient unless afterburners are in use. Unless data are otherwise available 100°F should be used in calculations.

GAS VELOCITY

Gas velocity ranged from 30 to 53 fps for the various rubber making processes. Fifty feet per second would seem a reasonable average.

STACK HEIGHT

Most of the stacks are located on the roof of the manufacturing building. One plant had stack heights (ground to top of stacks) of about 75 - 80 feet with stack diameters of 5 - 9 inches.

TABLE IV-15.1

Monomers And Major Chemicals Used For Manufacture Of Synthetic Rubber, 1970[16]

Monomer	Million lb.
Butadiene	2,273
Styrene	435
Acetylene	192
Ethylene	270
Propylene	180
Isoprene	240
Acrylonitrile	37
Isobutylene	205
Miscellaneous dienes	18
Chemicals	
Oils	1,131
Plasticizers	40
Zinc oxide	195
Stearic acid	110
Rosin	47
Carbon black	2,100
Accelerators	69
Antioxidants	76
High-styrene resins	60

TABLE IV-15.2

Exhaust Gases From Synthetic Rubber Plants[17]

Process	Production Capacity (lb./batch)	Exhaust Flow scfm	Stack Velocity fps	Stack Temperature (°F)
Fluidizing polyvinyl chloride powder	200,000	1600	50	100
Fluidizing polyvinyl chloride powder	200,000	1600	53	100
Fluidizing polyvinyl chloride powder	200,000	1600	53	100
Fluidizing polyvinyl chloride powder	200,000	1600	53	100
Polymerization of vinyl chloride	5,600	1800	47	75
Venting PVC vessel	--	2850	30	60

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CHAPTER V-1

ALFALFA DEHYDRATING PLANT [C]

The Nation's dehydrated alfalfa is produced primarily in the middle-west with Nebraska and Kansas accounting for 50 percent of total production.[2] A typical dehydrating unit requires the yield from 1,000 acres of alfalfa for economic operation. Operation is restricted to the growing season, approximately May through October depending on latitude. A typical plant will produce 2,000 to 5,000 lb./hr. of alfalfa meal and will operate 24 hours per day, 7 days per week during the season.

The alfalfa is finely chopped and fed into a gas- or oil-fired horizontal rotary drum where the moisture in the alfalfa is reduced to about 8 percent. The hot moist combustion gases and the dried alfalfa then are separated by a primary cooling cyclone. Sometimes a secondary cooling cyclone will be used to further cool the dried alfalfa before discharging the raw material to a hammermill for grinding.[1]

The alfalfa meal is conveyed by air to a cyclone; the meal goes to storage, and the air goes to the atmosphere. Auxiliary processes include pelletizing and pellet regrinding. Pollutants are limited to fine alfalfa particles. Baghouses are occasionally used on the effluents from processes other than the primary cyclone.

GAS FLOW RATE

Exhaust gases from the primary cooling cyclone are the greatest in volume of all sources in an alfalfa dehydrating plant. These are also the most difficult to control because of high moisture content. Gas flow rate from the primary cooling cyclone (the rotary dryer) was 15,320 scfm for a 3,000 lb./hr. alfalfa meal production rate and 8,090 scfm for a 2,100 lb./hr. production rate. Based on these two plants, one could estimate 4,500 scfm of exhaust gases per 1,000 lb./hr. of product produced. Secondary cooling cyclones for the two plants exhausted only about 600 scfm per 1,000 lb./hr. of production rate, and the hammermill exhaust (air/meal separator) averaged about 1,700 scfm per 1,000 lb./hr. Considering these three unit operations as one basic process, the total exhaust flow would be 6,800 scfm per 1,000 lb./hr. meal production rate (Figure V-1.1). Processes such as pelletizing average about 900 scfm per 1,000 lb./hr. of pellets produced, and one plant which reground pellets (14,000 lb./hr.) produced only 1,000 scfm total.[2]

GAS TEMPERATURE

The gas temperature of the drier exhaust as it exits from the primary cooling cyclone will be about 340°F, from the secondary cooling cyclone about 130°F and from the air/meal separator about 100°F. Auxiliary pelletizing or grinding processes can be expected to exhaust at about 120°F.

GAS VELOCITY

Gas velocity from cyclones is generally low to prevent re-entrainment of solids. For light dusts, 10 fps or less is often used. For the two plants which provided stack diameters, velocities ranged from 3 to 14 fps with both primary cooling cyclones running 10 fps. Stack diameters varied from 25 to 44 inches.

STACK HEIGHT

Stack heights for the two plants which provided data showed a range of 20 to 39 feet. One plant exhausted a portion of the effluent up an 85 foot stack, but this probably is uncommon. Thirty feet would seem more typical for dispersion work and calculations.

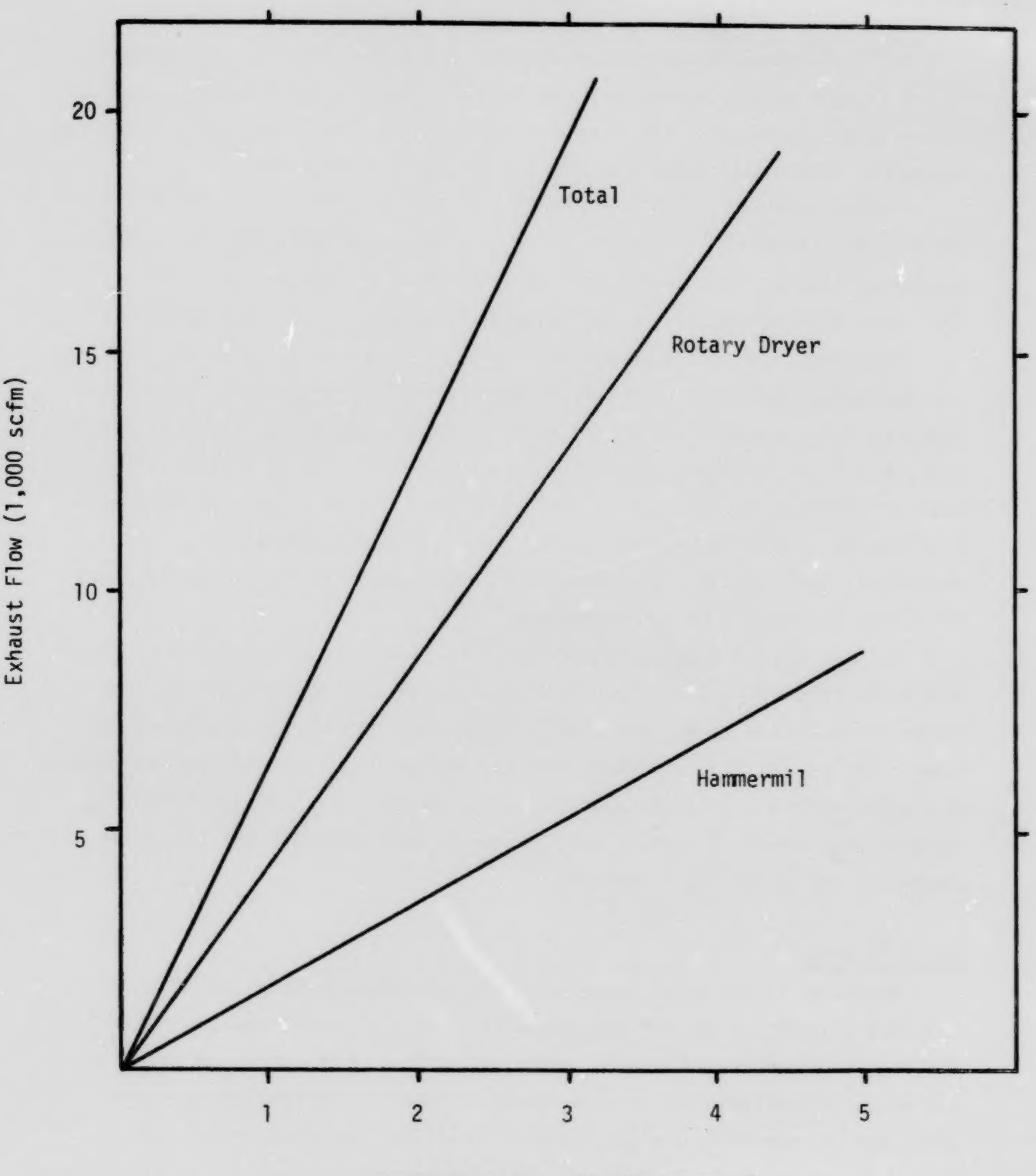

Figure V-1.1 Exhaust flow rates from alfalfa meal production

CHAPTER V-2

COFFEE ROASTING PLANT[B]

Coffee beans, primarily from Central and South America, are roasted in most major cities throughout the United States. The industry processes coffee beans throughout the year, but individual plants may operate certain equipment only a few hours per day depending on market demand.

Coffee beans are cleaned of dust and chaff, roasted, cooled and destoned, ground, and packaged.[4] (Figure V-2.1) A small percent, 30%, will later be processed into instant coffee and an even smaller percent, 5%, will have been decaffeinated with trichlorethylene prior to roasting.[15]

Principal air contaminants are dust and chaff from cleaning, cooling and destoning operations. These contaminants, although small in concentration, are generally collected with cyclones. From the roaster smoke, odor, steam, and larger quantities of particulates are generated. The common control procedure is to use a cyclone to trap course particulates followed by an afterburner to oxidize the odorous hydrocarbons, fine particles, and visible blue smoke. Several plants in New Jersey use wet scrubbers to abate roaster emissions.[14]

Solvent loss (trichlorethylene) is the additional emission discharged in the production of decaffeinated coffee; no controls are utilized. For instant coffee production, the roasted beans are ground and extracted with water (300°F, 10 to 12 atmospheres), and the solution is filtered to remove the spent solids.[4] The filtrate is spray dried. The instant coffee is removed with cool dry air at the bottom of the tower, and the hot, moist drier gases are exhausted to a scrubber.

GAS FLOW RATE

Roasting is the most important step in coffee making; it is also the most productive of air contaminants. Most roasters are gas-fired and recirculate exhaust gases; about 370 BTU of heat energy is required per pound of coffee. Batch type roasters without recirculation handle about 500 pounds of beans per batch (1,500 lbs./hr.) and discharge exhaust gases at about 1,000 scfm. If exhaust gas recirculation is employed the exhaust gas discharge will be reduced about 40 percent. On a common unit basis of 1000 lbs./hr. of beans processed, batch roasters without recirculation would discharge 660 scfm; with recirculation, 400 scfm per 1,000 lbs./hr. processed. Likewise, a 10,000 lb./hr. continuous roaster, with a recirculation system, exhausts about 4,000 scfm or 400 scfm per 1,000 lb./hr. processed (Table V-2.1).

Continuous type stoners exhaust about 40 scf per pound of finished coffee, while batch type stoners vary between 80 and 200 scf per pound of coffee. The operation of stoners requires a constant gas velocity so air volume would vary with plant capacity but probably not with production rate (percent of capacity).

Continuous type coolers exhaust approximately 120 scf per pound of finished coffee. Batch coolers generally use about 200 scf per pound. Cooler air flow would probably not vary much with production rate (percent of capacity) as was the case with stoners.

Effluent from a 2,000 lb./hr. instant coffee spray drier would be about 8,000 scfm. The stack gas flow rates for roasters, coolers, and stoners are shown in Figures V-2.2, V-2.3 and V-2.4 respectively.

GAS TEMPERATURE

Recirculation type roasters typically exhaust to the cyclones at 1,000°F. There should not be more than 100-200°F of temperature loss by the gases before they exit the stack at about 800°F. Units with afterburners will have outlet temperatures to the stack of about 1,200°F.

Temperatures of cooler off gases are not well documented, but the beans are discharged from the quenching step at an estimated 250 to 300°F, and the cooler exhaust gases would be somewhat less than this, possibly 150 to 200°F. The temperature would decrease to ambient in batch coolers. Stoner exhaust gases are at approximately ambient temperature, because this is essentially an airveying step. The temperature of the effluent from the spray drier for making instant coffee ranges from 200 to 400°F.

GAS VELOCITY

No data were available on stack diameters or exit velocities. Induced draft fans are used for draft control of coffee roasting operations. Recommended design velocities for ducts and stacks with fan-powered draft are about 25 fps for economical operation.[6] Assume 20 fps.

STACK HEIGHT

No data were available. However, one plant which was tested had stacks about 5 feet higher than the roof which topped a 3-story facility. Total height for the roaster and cooling stacks would therefore be 35 feet. The drier for instant coffee may be 20 feet in diameter and up to 80 feet high. Therefore, assume a stack height of 100 feet for it.

TABLE V-2.1

Exhaust Gases from Coffee Roasting Plant[14]

Operation	Input Rate lb./hr.	Exhaust Flow scfm	Exhaust Temp. °F	Exit Velocity fpm	Stack Height ft.	Operating Time	Control Equipment
Roaster	3250	5,000	110	2900	115	7.5 hr./day, 16 day/mo.	2 scrub
	3250	2,500	100	1450	115	7.5 hr./day, 16 day/mo.	2 scrub
	3250	5,000	150	2900	115	7.5 hr./day, 16 day/mo.	cyclone/scrub
4 Roasters	9000	35,000	125	2100	135	15 min./batch	chem. scrub
4 Roasters	5000	84,000	150	730	102	15 min./batch	
24 Roasters	9000	325,000	100	1075	68		wet scrub
12 Roasters	1200 lb./bat.	3,300	80	2200	110	600 bat./wk.	dry cyclone
4 Roasters	420 lb./bat.	959	1050	253	32	15 min./batch	gas after-burner
4 Roasters	420 lb./bat.	2,919	950	548	45	15 min./batch	gas after burner

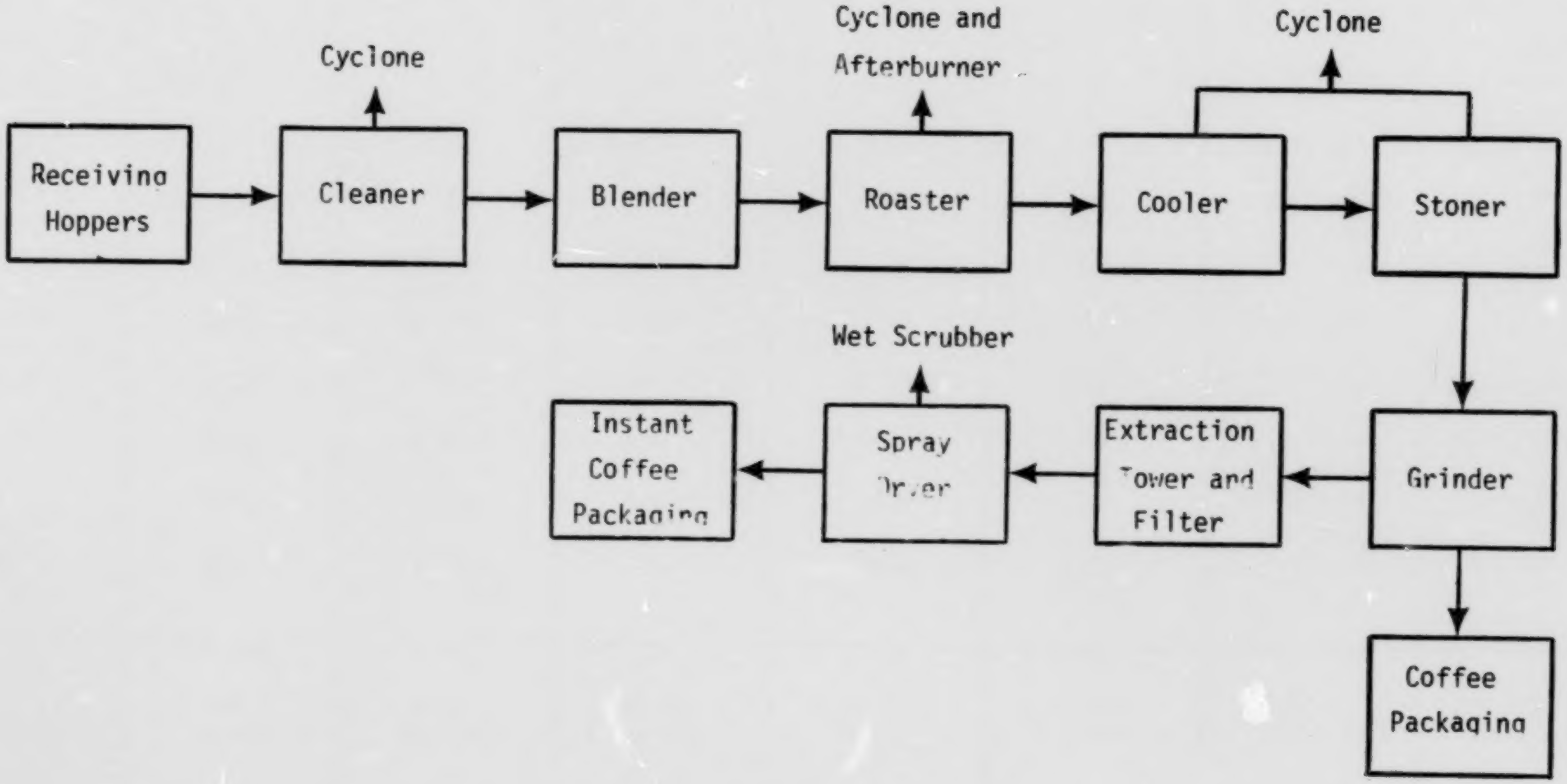
Receiving Hoppers
Cleaner
Cyclone
Blender
Roaster
Cyclone and Afterburner
Cooler
Cyclone
Stoner
Grinder
Coffee Packaging
Extraction Tower and Filter
Spray Dryer
Wet Scrubber
Instant Coffee Packaging

Figure V-2.1 Flow diagram for coffee roasting and instant coffee operations

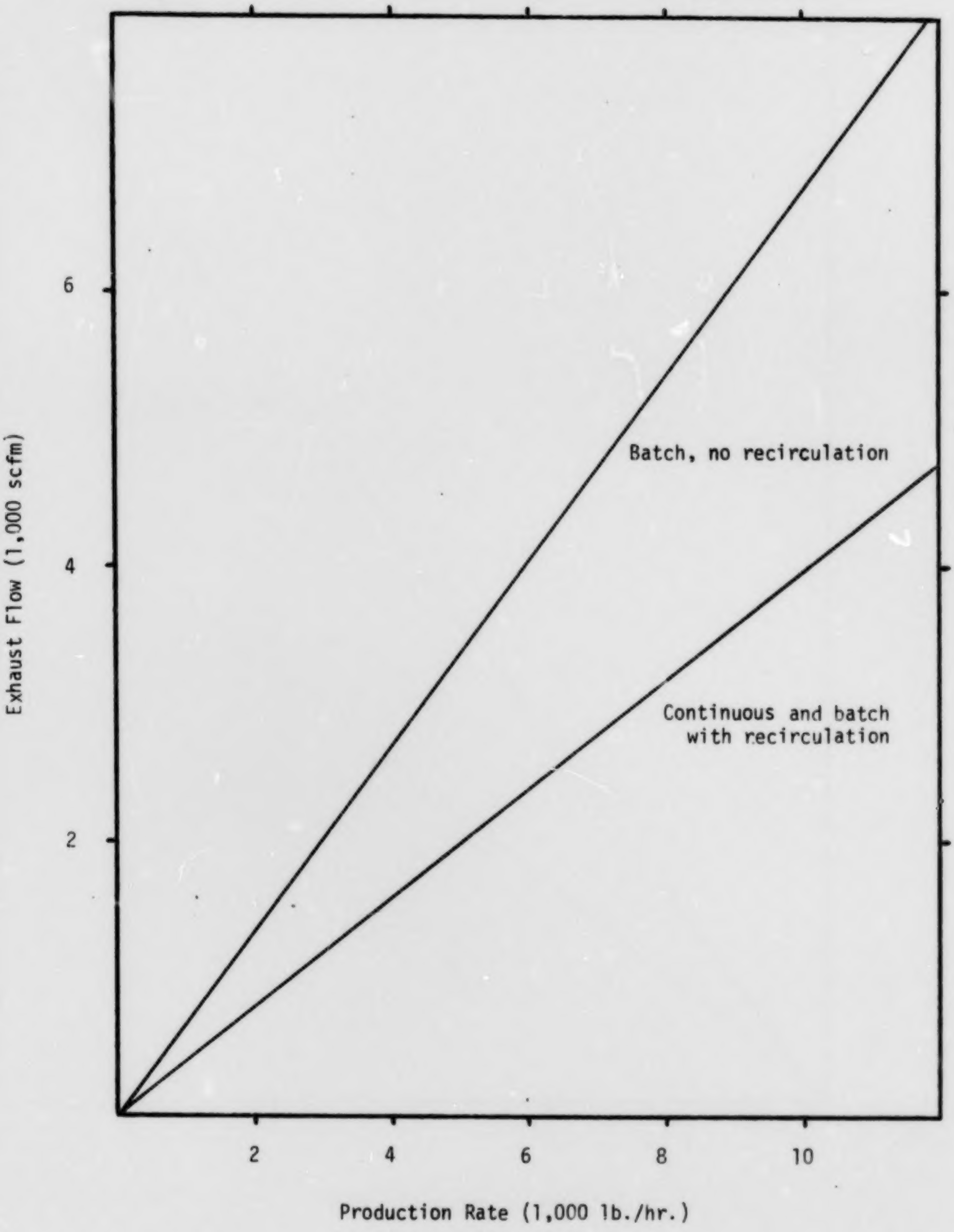

Figure V-2.2 Exhaust flow rates for coffee roasters

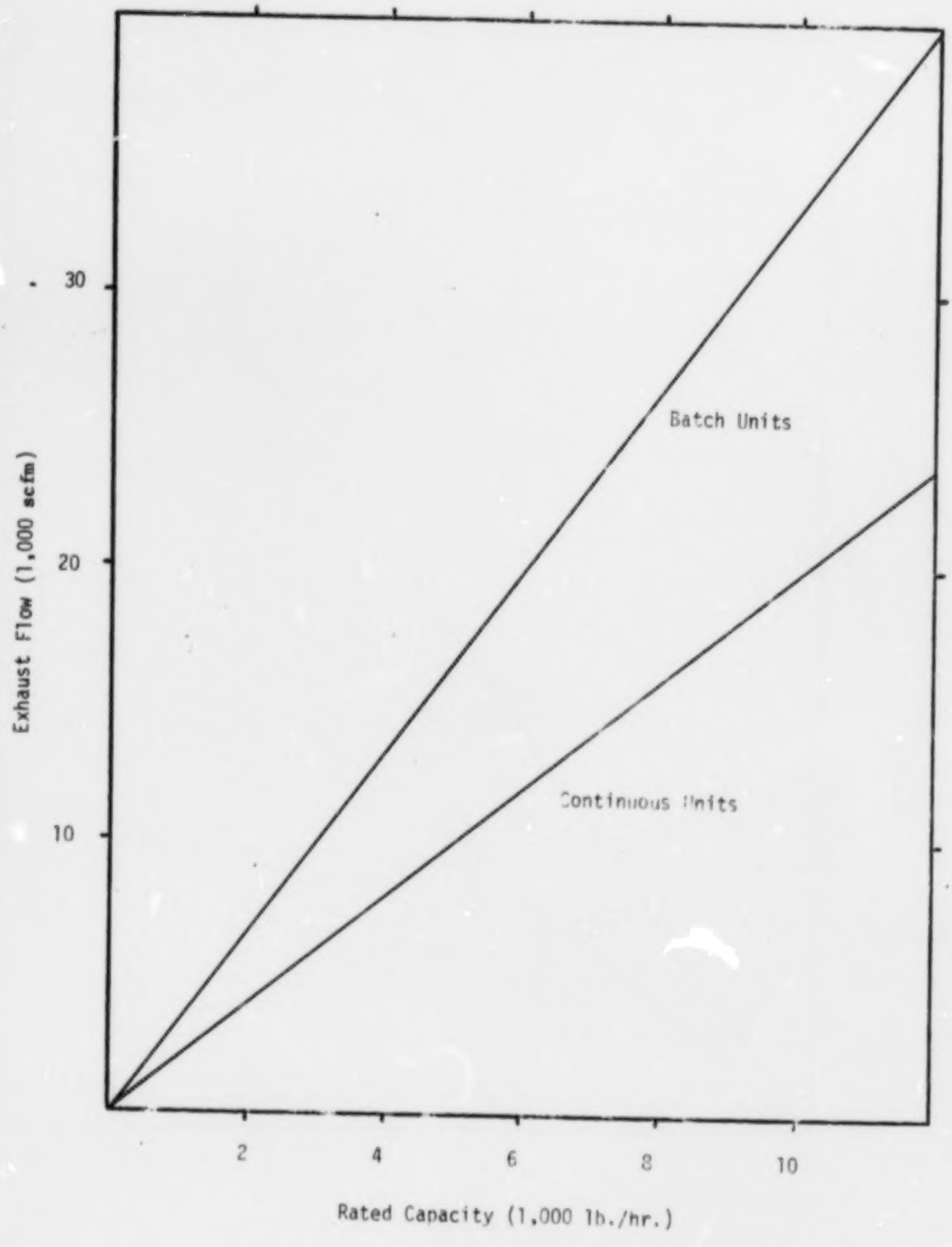

Figure V-2.3 Exhaust flow rates for coffee coolers

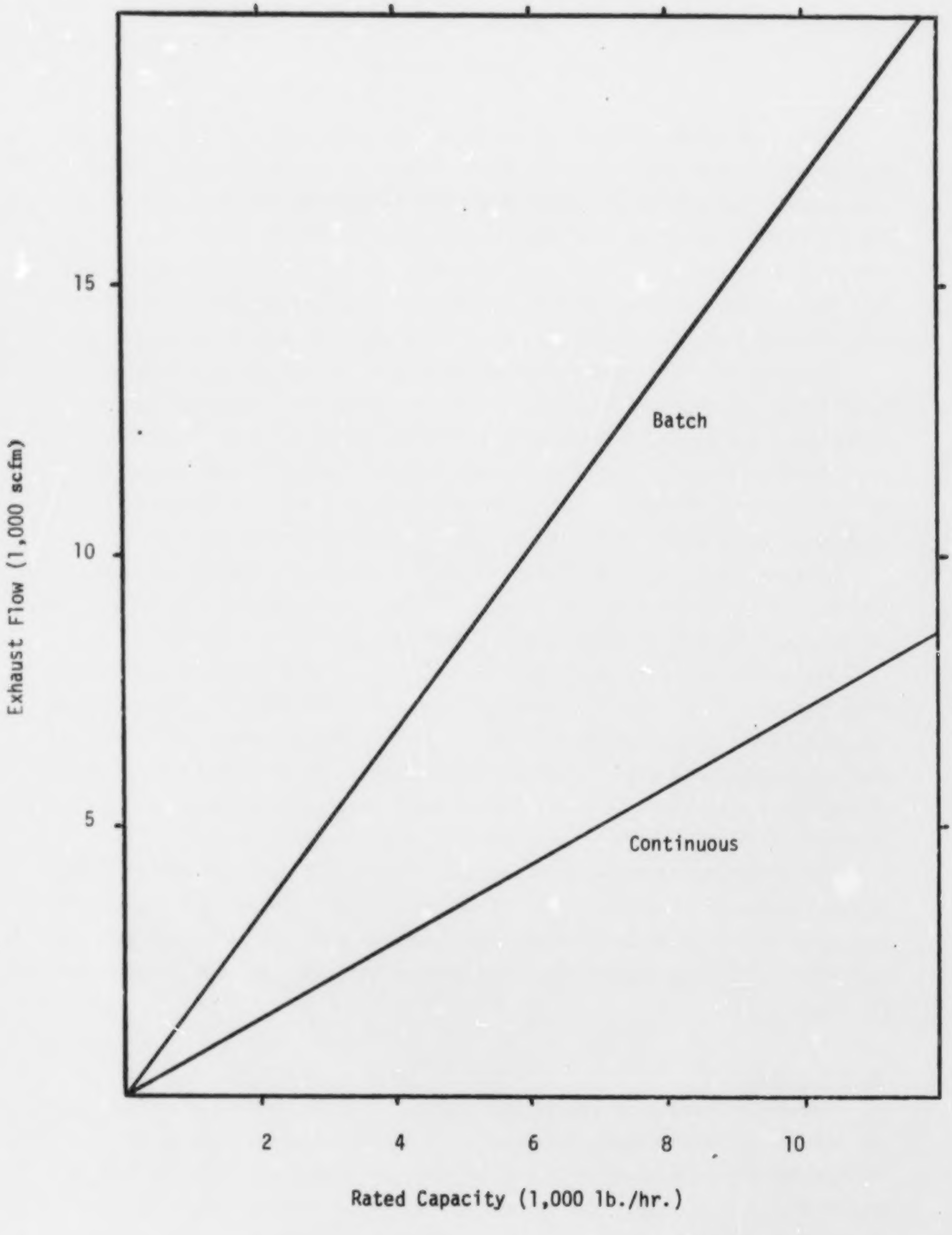

Figure V-2.4 Exhaust flow rates for coffee stoners

CHAPTER V-3

COTTON GINNING PROCESS [C]

Cotton is grown in 15 or 20 of the southern states from California to Florida with Texas accounting for about 25 percent of the Nation's total production. The cotton is picked primarily by machine and delivered to a local gin for processing. At the present time, there are close to 5,000 cotton gins in the U. S. Each operates only from 4-8 weeks out of the year when the cotton is harvested (usually between June and October). During the harvest owners try to operate the gin 7 days per week and 24 hours per day.

A survey of Texas gins in 1965 showed that the average gin handled 3,233 bales per year and that the break even point for a marginal gin was 2,108 bales per year. Arizona and California, which are considered high-yield cotton growing areas, had average ginning rates of 5,300 and 6,000 bales per year, respectively. A typical cotton gin will have the capacity to process and produce about 12-15 bales of cleaned cotton per hour.[7]

Ginning cotton consists essentially of cleaning the cotton and separating cotton lint and seeds from the trash. The lint is compacted into 500 lb. bales for shipping to textile mills, and the seed is shipped to oil mills.

The amount of trash which must be removed from the cotton depends to a great extent on the way the cotton is harvested. In 1966, 78 percent of the cotton crop was harvested by machine, 58 percent with pickers and 19 percent with strippers. One percent was machine scrapped. Of the remaining 22 percent of the crop, 16 percent is hand- picked and 6 percent hand- snapped.[7] The trash consists of hulls, sticks, stems, leaves, and dirt (Table V-3.1).

The principal emission from the gins consists of dust and cotton lint. Control equipment is generally small diameter cyclones which are used for air-conveying and air separation operations. A secondary source of air pollution at many gins is the jug (tepee) type incinerator which may be used to burn cotton gin trash.

GAS FLOW RATE

Exhaust volumes from cotton gins are quite high, because air-conveying and air-separation are used extensively. Table V-3.2 shows typical gas volumes for the components of a cotton gin. Note that not all gins have a second drying operation. The volumes are given in acfm, but ordinary exhaust temperatures differ little from ambient temperatures so that correction to scfm is unnecessary. In spite of the heat-input from the burner on the drier(s), the very large amounts of air from other operations and system leaks lower the temperature considerably.

It is common practice to place all but one of the cyclones in a battery beside the gin building so that all can discharge to a common conveyor. Collected trash is in turn blown into a bur house or incinerator. The lint cleaner trash fan effluent is preferable for such use since fine lint tends to clog the conveyor.

Assuming the gas flow rates of Table V-3.2 are appropriate for an average gin, then the design exhaust flow vs. capacity would be 43,500 scfm for processing 12 bales per hour or about 3,000 scfm per bale/hr.

GAS TEMPERATURE

With the exception of the drying system, all operations in the cotton gin are conducted at ambient temperature. Dryer temperature is set to maintain 6.5 to 8 percent moisture in the dry cotton fibers and it, therefore, varies depending on the moisture content of the raw cotton. However, cellulose, the principal component of cotton, shows marked decomposition at 284°F or higher.[8] Because of this, termperatures out of the dryers are not expected to exceed 200°F. For dispersion calculations total exhaust temperatures of 100°F should be assumed.

GAS VELOCITY

To prevent re-entrainment of particulate matter collected in the cyclones, the cyclone stack velocity should not exceed 8.3 to 10 fps according to the U. S. Cotton Ginning Research Laboratory. This suggests that a design gas flow rate of about 10 fps would probably be maintained, even when ginning at reduced load, (to retain particle removal efficiency).

STACK HEIGHT

No data were available on stack height. However, since the cyclones are located beside the gin building (most operations are at ground level) a total stack height of 30 feet is probably equal to or higher than most cotton gin stacks.

TABLE V-3.1

Average Amount and Type of Trash In Seed Cotton Harvested By Various Methods (lb./bale)

Types	Machine picked	Machine stripped	Machine scrapped
Hulls	29	397	329
Sticks and stems	9	50	143
Leaf and dirt	43	78	398
Total	81	525	870

TABLE V-3.2

Air Volumes Utilized In Various Seed Cotton Trash-Handling Systems (Based on 12 to 15 bales/hr.)[7]

System	Air Volume (scfm)
Trailer unloading	8,500
No. 1 drying and cleaning system	9,000
No. 2 drying and cleaning system	9,000
Live overflow	4,000
Trash fan	3,000
Lint cleaner trash fan	10,000
Total (1 dryer)	34,500
Total (2 dryers)	43,500

CHAPTER V-4

FEED AND GRAIN MILLS [c]

The Nation's supply of feed and grain for both human and livestock consumption is grown throughout the U. S. but is centered in various belts. Corn is the most important agricultural crop in the U. S. The corn belt is centered in the Mississippi River Valley, Iowa and Illinois primarily. Wheat, which constitutes the second most important food crop in the U. S., is grown primarily in the west central states from North Dakota to the Texas panhandle. Other domestic grains include oats, barley, flax and rye, each of which is grown in those areas where climate and soil conditions are most favorable. The largest concentrations of feed and grain mills (elevators) are found in such cities as Chicago, Minneapolis and Duluth, but there are literally thousands of feed and grain mills located throughout the U. S.

Because of the different grains handled, the type of dust emission will vary somewhat. Corn cleaning or processing will discharge small particles of cob fiber called "bees wings"; wheat processing will release "chaff", etc. Dust emissions are the sole contaminant from feed and grain mills. This dust is generated by feed manufacturing processes as well as unloading, conveying, and storing the feed and grain. Manufacturing processes include cleaning, grinding, rolling, pelletizing, regrinding, and blending. Pelletizing and regrinding of alfalfa meal are discussed in Chapter V-1, Alfalfa Dehydrating Plants, and the results in that section should be somewhat applicable to other feeds as well. Dust laden air from grinders, rollers, hammer mills and cleaners is usually cleaned by a cyclone. At times, filter baghouses may be used to further purify the cyclone exhuast. See Figure V-4.1.

A model grain elevator chosen to represent a typical operation of a flour or animal feed operation processes 12,600 lb./hr. of material and is operated 6800 hr./yr.[10] This is equivalent to operating 24 hr./day for between 5 and 6 days per week during the year. Small elevators generally operate 24 hr./per day, 7-days a week only during the harvest season and revert to 8 hr./day operations the rest of the year.

GAS FLOW RATE

Unloading of grains is usually done in one of three ways: (a) the choked-feed method (which produces little or no dust or exhaust flow), (b) deep receiver dumping, or (c) pneumatic conveying. Emissions from deep receiver dumping are sometimes controlled by an exhaust hood, and the air used in the pneumatic conveyer is commonly cleaned by use of a cyclone separator.[3]

An exhaust hood proposed for one deep receiver unloading area exhausted 12,000 scfm of air from a 600,000 lb./hr. grain dumping operation.[9]

Recommended transport velocities for common grains conveyed pneumatically are in the range 4000 to 7000 fpm.[3] With the commonly used 5-in. duct, this would be an air flow range of 545 to 953 scfm. Typically, a value of about 750 scfm could be used.

Table V-4.1 and Figure V-4.1 show exhaust gas volume flow rates for grain cleaners and a hammer mill versus grain throughput capacity. Air flow in these operations would be set by equipment design capacity rather than operating rate. In general, the flows range from 50 - 5000 scfm per 1000 lb./hr. of grain processed in each operation.

GAS TEMPERATURE

All equipment in feed and grain mills usually exhausts at or very near ambient temperature; therefore, 70°F should be used where actual conditions are unknown.

GAS VELOCITY

Cyclones are commonly used for dust removal in feed and grain mills. To prevent re-entrainment of dust, the exhaust velocity of these units is typically no more than 8.0 to 10.0 fps.[7] No actual operating data were available.

STACK HEIGHT

Grain elevators utilize tall silos for storage of grain and feeds. As a result, cyclones used for conveying the products are also located at high elevations. No data were available, but 150 feet is probably typical.

TABLE V-4.1

Exhaust Gases from Feed and Grain Mills[3]

Operation	Grain	Process Weight lb./hr.	Exhaust Volume scfm
Cleaning	Malted Barley	53,000	2,970
Cleaning	Malted Barley	50,000	2,970
Cleaning	Milo	11,250	6,290
Milling (Hammermill)	Feed Barley	10,350	3,790

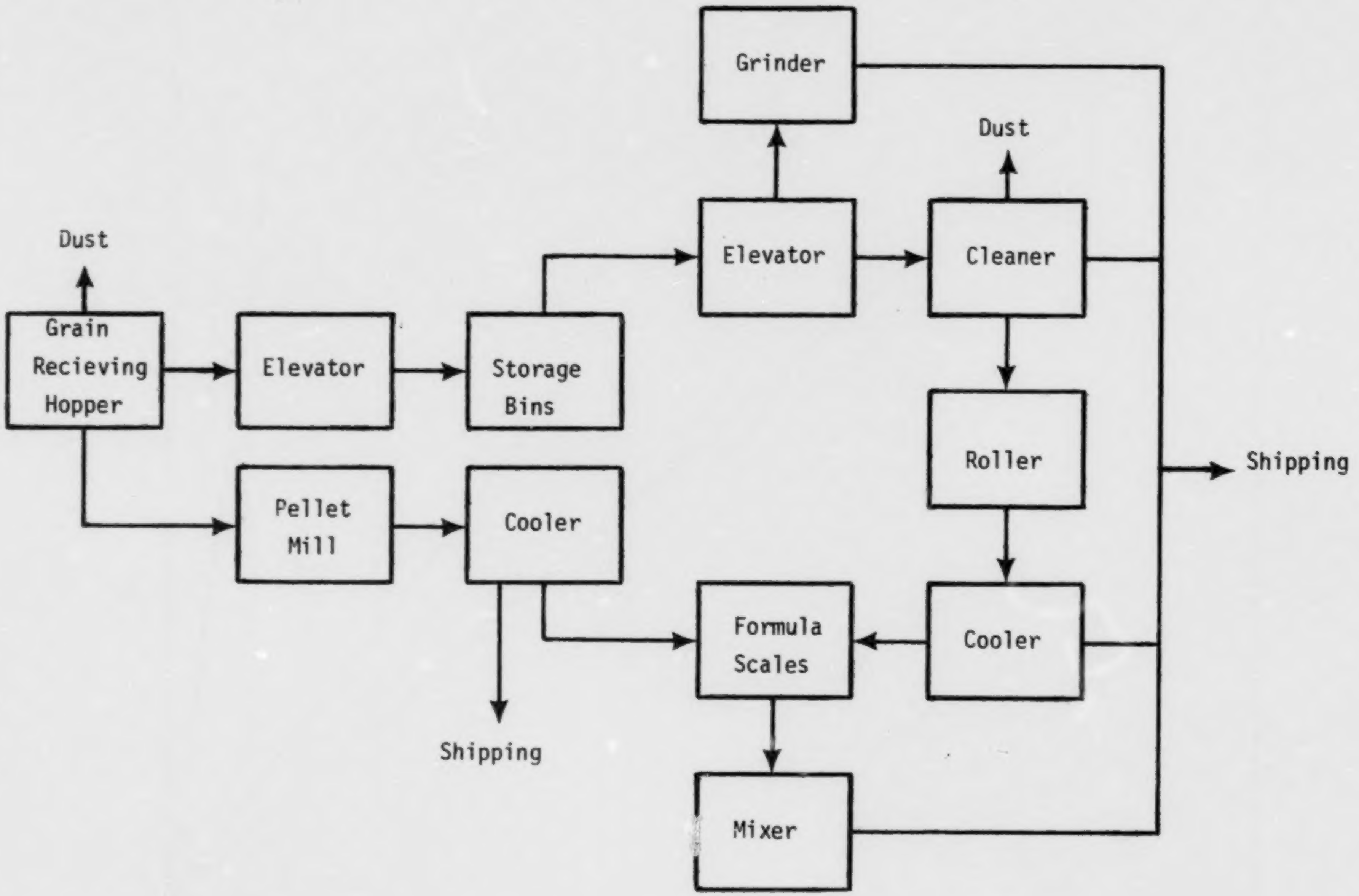
Dust
Grain Recieving Hopper
Elevator
Storage Bins
Pellet Mill
Cooler
Shipping
Grinder
Elevator
Dust
Cleaner
Roller
Cooler
Formula Scales
Mixer
Shipping

Figure V-4.1 Flow diagram for feed and grain mill operations

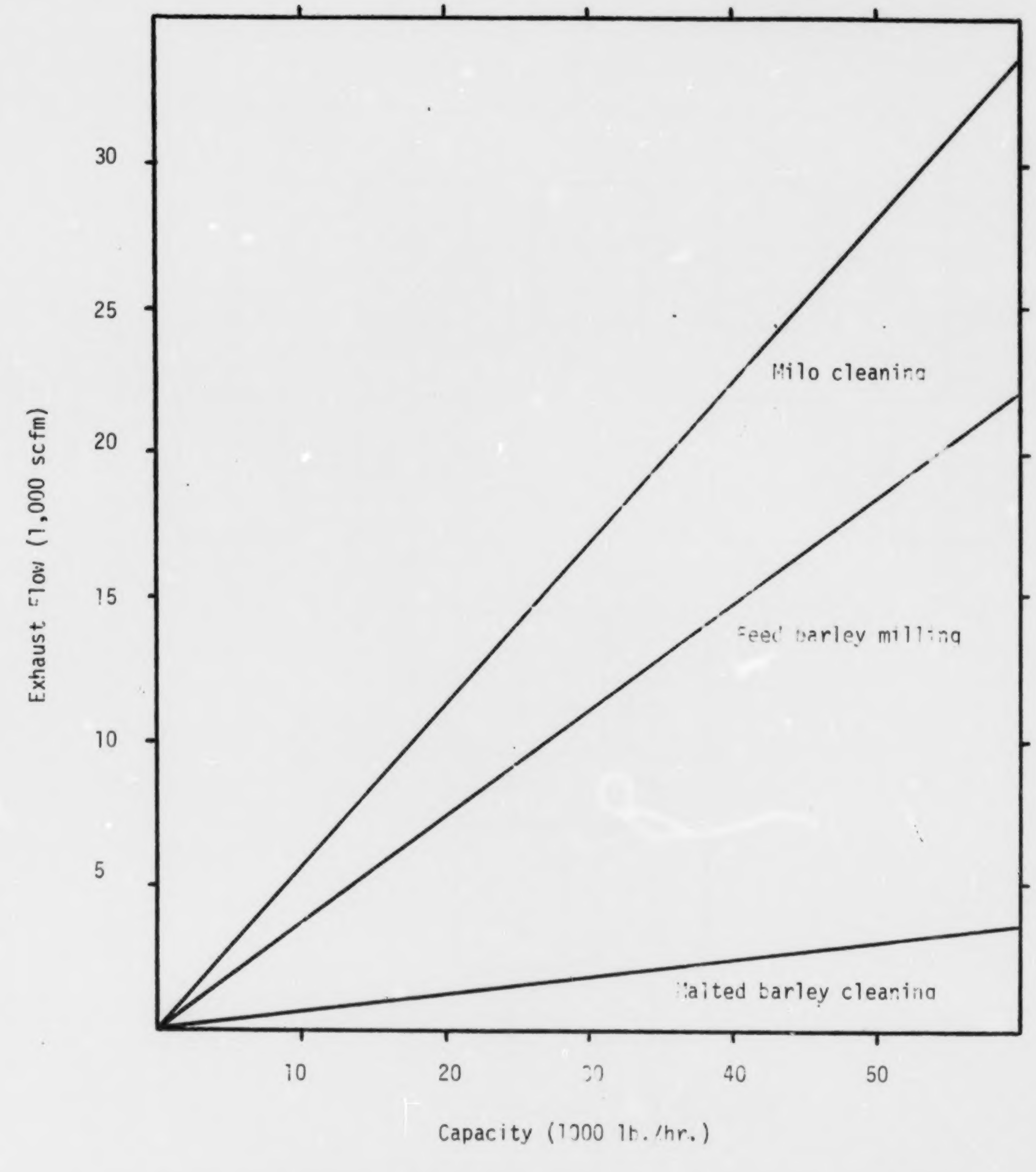

Figure V-4.2 Exhaust volumes for grain cleaning and milling operations.

CHAPTER V- 5

FISH MEAL PROCESSING [c]

Fish canneries generally are located near the U. S. coasts or other large bodies of water. Fish scraps from the canning lines, including any rejected whole fish, are taken to by-product plants located nearby and processed into fish meal. Fish oil and fish solubles are of lesser economic importance as by-products. The fish meal subsequently is used for fertilizer or animal food.

The chief processes in the manufacture of fish meal are: (a) cooking solid fish wastes at 2 to 5 psig with live steam, (b) pressing the cooked waste to remove liquids, (c) grinding the press-cake, (d) drying the coarse solids in a rotary drier, and (e) regrinding the dried fish meal before conveying it to storage.[3]

Emission points for air contaminants include each of the processes, the cooker exhaust, the presses and grinders, the rotary drier exhaust, and exit gases from the air-conveying system used for transporting the finished meal. Cooker off gases usually are passed through a contact condenser for removal of water vapor and oils before exiting to the atmosphere. Emissions, primarily odors, are generated by the presses and grinders, but such operations may or may not be controlled. Tremendous volumes of steam plus small quantities of fish meal and significant amounts of odors are discharged from the rotary drier. Emissions from the conveyers are chiefly fish meal dusts which are removed effectively by cyclone separators.

Operating times for fish meal plants obviously depend on the seasonal availability of raw materials, and the availability varies greatly. However, one such operation was found to operate for two 8-hour shifts per day and 5 days per week.

GAS FLOW RATE

The largest contaminated gas stream is exhausted from fish meal driers. Volume emission rates are greater by 70% from direct-fired units as compared to steam-tube driers (Table V-5.1). Also, the exhaust is cooler and the moisture content of the gases is greater from the steam-tube drier. From the one set of available test data, the dry exhaust gases from a steam-tube drier can be expected to total 500 scfm per 1,000 lb./hr. of feed to the drier (Figure V-5.1). With a 5 ton/hr. input the direct-fired unit would discharge 10,000 scfm dry and produce 2.5 tons/hr. of dried meal.

Fish meal pneumatic conveyor systems are designed to provide 45-70 cubic feet of air per pound of meal conveyed. Thus, for a 5 ton/hr. conveyor the exhaust would be about 10,000 scfm.

Total from the plant will be about 2,000 or 3,000 scfm per 1000 lb./hr. dried fish meal processed and handled by the steam-tube and direct-fired drier plant, respectively.

From the cooker, the pop-off gases (mostly steam), total from 100-1000 scfm depending on design. These gases are invariably exhausted to a condenser where steam and all other condensables are removed. Non-condensable gases seldom exhaust more than 50 scfm and are ignored in this report.

GAS TEMPERATURE

The temperature of the exit gases from the driers will be about 200°F, while that from the conveyor will be near ambient 65°. The average exhaust gas temperature, therefore, will be about 150°F.

GAS VELOCITY

The use of cyclones on both the drier exhaust and the conveying system suggests that the exit velocity would be on the order of 10 fps. No data were available.

STACK HEIGHT

No data were available; however, stack height is expected to be on the order of 30 feet from observations at one similar plant.

TABLE V-5.1

Exhaust Gases from Fish Meal Processing Plants[14]

Input Rate lb./hr.	Exhaust Flow scfm	Exhaust Temp. °F	Exit Velocity fpm	Stack Height ft.	Operating Times	Control Equipment
40,000	15,000	120	2400	70	10 min./batch, 48 batches/day	Cyclone
24,000	15,000	150	2400	70	10 min./batch, 48 batches /day	Cyclone

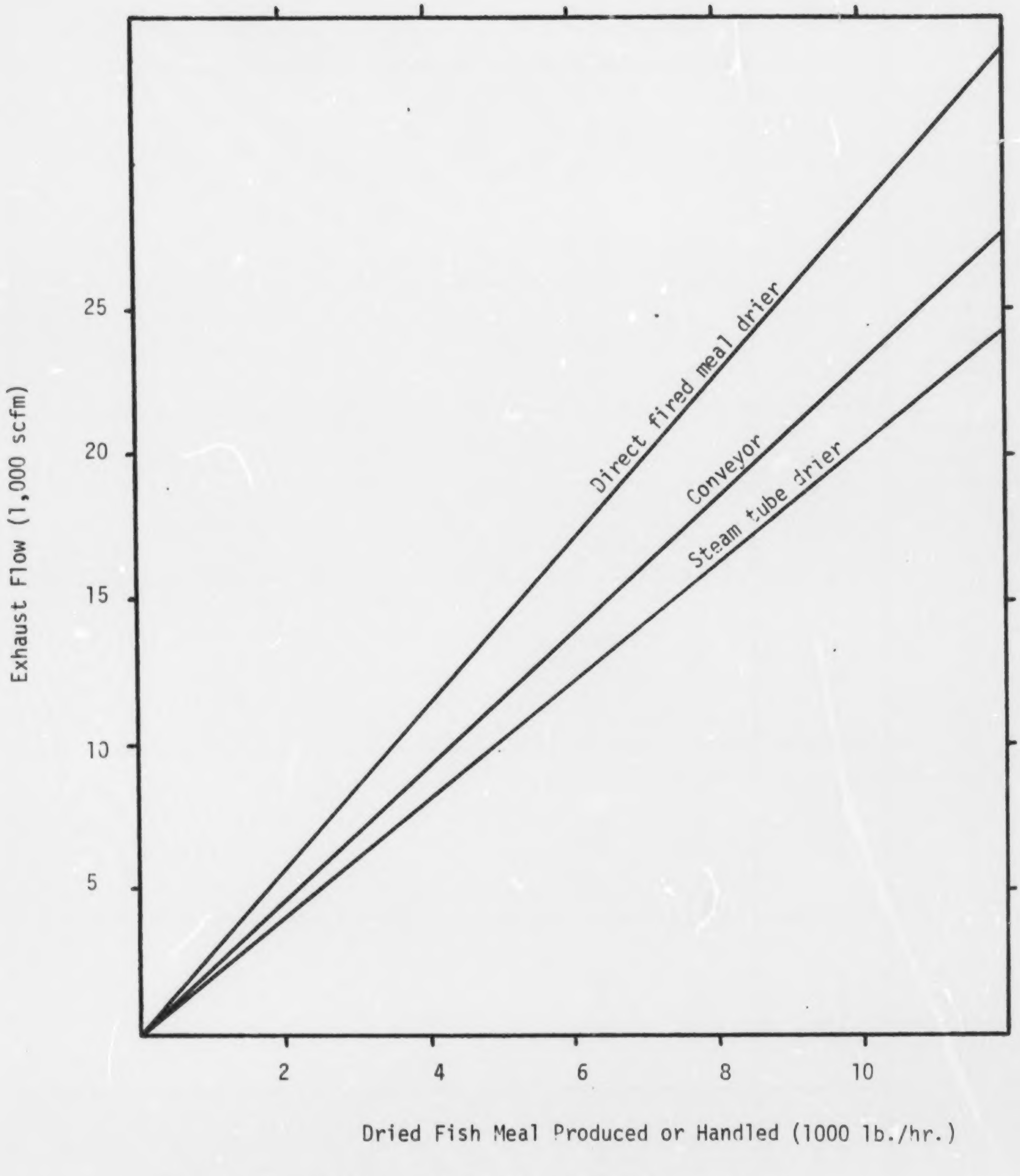

Figure V-5.1 Exhaust volumes for fish meal operations

CHAPTER V-6

FERMENTATION PROCESSES [D]

Fermentation process industries are similar to the chemical process industries with the exception that the emphasis is on the reaction created by microorganisms instead of chemicals. Fermentation processes include the manufacture of beer, wine and liquors, the manufacture of yeast, and the production of pharmaceutical drugs like penicillin. It is imperative that the fermenter (main reaction chamber) be immaculate to prevent bacterical contamination. Fermentation processes are entirely closed with the major emission point being small vent lines which operate intermittently and at very low flow rates.[16] The fermenters determine plant capacity and have typical sizes which range from 50,000 to 100,000 gallons.[16]

The major air pollutants from fermentation processes are odorous gases which originate from the fermentor where controlled volumes of air are passed over the media and microorganism bed. Plants operate 24 hours a day and 7 days a week. No information was available, but control equipment would likely be limited to filters on ventilation air which are changed and burned daily and afterburners on some vent lines.

GAS FLOW RATE

Gas flow rate from these plants is very low and will be less than 1 scfm for a 50,000 gallon fermenter. If a plant had 20 fermenters running continuously, the total exit flow rate would only be 20 scfm.

GAS TEMPERATURE

The gas exit temperature for these plants is ambient for all practical purposes since the temperature in the fermenter is usually about 85°F.

GAS VELOCITY

One process has a gas velocity from the fermentor which ranges from 1 to 4 fpm.[16] Since gas velocity from these plants is so small, no plume rise can be expected.

STACK HEIGHT

Plants will not normally have a stack for the fermenter gases but will usually have roof top vent pipes 4 to 6 inches in diameter. The stack height will be the height of the plant building. Most breweries have a plant height of about 80 ft., while pharmaceutical plants have a height of about 35 feet. For calculations assume 50 feet.

CHAPTER V-7

MEAT SMOKEHOUSES[c]

The technique of smoking to preserve meat and fish products has been used for centuries. It was originally developed as a method for preserving food products, but curing and storage processes have improved to the point where smoking is now used only to impart flavor and color to the food products.

The two most common types of smokehouses are: (a) atmospheric smokehouses, and (b) recirculating smokehouses which are operated intermittently anywhere from 1 hr./day to 24 hr./day. The major air contaminant from meat smokehouses is smoke, fine particulates which are rarely controlled. The older atmospheric type is a boxlike structure heated directly by natural gas or wood, equipped with a natural draft circulation system. Newer smokehouses are usually of the recirculating type in which smoke is circulated at fairly high velocities over the curing products; smoke is piped to the house from generators outside. These operations would be few in number and would be associated with meat packing or fish processing plants.

GAS FLOW RATE

Exhaust flow rates from smokehouses are related to the floor area of the units rather than the weight of product being cured. Typically, this is about 2.5 scfm per sq. ft. for atmospheric smokehouses. Exhaust flows of recirculation smokehouses are 1 to 4 scfm per sq. ft. during smoking and cooking, and 4 to 9 scfm per sq. ft. during the drying cycle. For multiple-story units, total floor area can be used to obtain a rough estimate of exhaust flow rates.[3]

GAS TEMPERATURE

Exhaust temperatures for atmospheric smokehouses vary from 120 to 150°F.[3] Because the temperature requirement within the unit is the same for recirculating smokehouses, the exhaust temperature would be in the same range. For calculations assume 150°F.

GAS VELOCITY

No data were available for meat smokehouse gas flow emissions or gas velocity. However, other food process categories have low flow rates and low exit velocities. For dispersion calculations 5 fps is recommended.

STACK HEIGHT

No specific stack data were available. Since smokehouses are commonly found around meat packing plants, the expected stack height would be 20 to 50 feet. Assume 30 ft. for calculations.

CHAPTER V-8

STARCH MANUFACTURING PLANT[D]

In 1964, 97% of the 5.8 billion lb. of starch produced in the United States was cornstarch.[11] The only significant air pollutant emission point of a cornstarch plant is exhaust from the drying operation. The dryer is usually a natural gas direct-fired flash unit or a continuous-tunnel countercurrent type. The emitted pollutant is cornstarch particles. It is common to find cyclones used but mainly to entrain dust from transport conveying systems. Large plants of this type typically operate 6 to 7 days per week, 22 hours per day.

GAS FLOW RATE

One large starch manufacturing plant (18,200 lb./hr.) had an exhaust flow of 35,000 scfm prior to installation of a gas scrubbing system. After installation of an effective scrubber, the exhaust flow decreased to 32,000 scfm.[13] Since no other data were available, use 2 scfm per lb./hr. of cornstarch processed as the exhaust flow rate.

GAS TEMPERATURE

Exhaust temperature for the one installation was 140°F.

GAS VELOCITY

The gas exit velocity prior to scrubber installation was 97 fps from a 36 in. i.d. stack. With the scrubber, velocity dropped to 89 fps in the same duct. These are very high velocities, but they might have been necessary to maintain the efficiency of twin cyclone separators which were located ahead of the scrubber in this particular system. For calculations 60 fps is recommended.

STACK HEIGHT

No specific data was available for stack height. For modeling purposes use 75 feet.

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CHAPTER VI-1

PRIMARY ALUMINUM SMELTER^{D}

Aluminum use in the U. S. is rapidly growing; 1968 production of aluminum totalled 3.4 million tons, an increase of 10 percent over 1967. There are 27 primary aluminum smelters in the United States with plant capacities ranging from 80,000 to 275,000 tons per year, with an average plant capacity of 150,000 tons per year.

Bauxite, a hydrated oxide of aluminum, is the base ore for primary aluminum production. It contains 30 - 70% Al_2O_3 and lesser amounts of iron, silicon, and titanium. Most ore is purified by the Bayer process. It is dried, ground in ball mills and mixed with sodium hydroxide solution in an autoclave to react with Al_2O_3 to form sodium aluminate. Impurities are removed by settling and filtration, and aluminum hydroxide is precipitated. The precipitate then is calcined to produce pure alumina, Al_2O_3.

Recovery of aluminum metal from the oxide is accomplished by the Hall-Heroult electrolytic process. Alumina is dissolved in a fused mixture of fluoride salts in carbon lined pots and dissociated electrically into metallic aluminum and oxygen. Aluminum is drawn off at intervals and alumina is steadily fed onto the top of the molten electrolyte.

Calcining of aluminum hydroxide to alumina generates dust which is generally controlled by cyclones and precipitators.

Electrolytic reduction generates carbon particles and alumina dust (300 lb./day) and both particulate and gaseous fluorides (75 lb./ton). Use of chlorine gas for fluxing and degassing the molten metal generates aluminum chloride which reacts with moist air to form aluminum oxide and hydrogen chloride. Controls include precipitators, baghouses and high energy scrubbers. Primary aluminum smelters operate continuously, 24 hours a day and 7 days a week.

GAS FLOW RATE

Typical exhaust flow rates for vertical cells range from 300 - 600 scfm/pot; for prebaked and horizontal cells the range is 1800 - 3500 scfm/pot.

GAS TEMPERATURE

Gases leave the electrolytic pots at temperatures between 1700 - 1800°F and are mixed with ventilation air prior to gas treatment. If these gases are vented to the atmosphere or if dry air pollution control equipment is utilized, exit gas temperatures will be about 300°F.[1] This temperature is primarily a result of the dilution air. A typical gas treatment system consists of dry dust collectors to remove particulates, water spray scrubbers for removal of gaseous fluorides and stacks for final dispersion of scrubbed gases. When water sprays are used, the temperature of the exit gases will be about 150°F.

GAS VELOCITY

No data were available,but exit velocities in the range of 25 to 50 fps would be expected.

STACK HEIGHT

No data were available, but stack heights can range from 100 - 500 feet depending upon the design criteria established for each plant site.

CHAPTER VI-2

PRIMARY COPPER SMELTER [A]

Primary copper smelting is currently practiced in 16 plants within the United States, all but two of which are west of the Mississippi River. Arizona alone contains 8 of the 16 copper smelters. Primary copper smelters are generally operated seven days a week, 24 hours per day, except for occasional scheduled and unscheduled shutdowns. The capacity and operating data for each of the 16 primary smelters in the United States are available, but such detail was not appropriate for this report.[2]

Copper is smelted from sulfide ores which account for 94 percent of the copper mined domestically. Smelting is comprised of three pyrometallurgical steps (Figure VI-2.1):

Roasting

Reverberatory furnace smelting to produce a copper matte.

Conversion of the matte to blister copper.

Nearly half of the smelters roast a charge of mixed concentrate and flux in a fluidized bed. Capacities vary from 700 - 1500 tons (dry weight) of feed per day. Roasting is required when the feed material is low in copper and high in iron and sulfur. Roasting is done at about 1200°F. The reverbatory furnace operates at 2400°F with feed rates of 400 - 1100 tons/day forming the matte and slag. Molten matte is transferred by ladles to the cylindrical converters which have a capacity of about 135 tons/day of copper from average matte. Generally, two converters are required for each reverberatory furnace.

Emissions from smelters consist of fumes (oxides of the metals being smelted) and sulfur oxides. Control equipment at present is limited to electrostatic precipitators (efficiencies 95-99%) for reducing particulates. Five sulfuric acid units for recovery of SO_2 have been added in recent years, and more are planned.

GAS FLOW RATE

As seen in Table VI-2.1 it is common for one stack to handle the exhaust gases from more than one furnace. This situation is representative of 6 of the 16 currently operating smelting facilities. Because of this practice it would be difficult to relate total stack gas flow rates directly with plant capacity. Therefore, the volume of gases emitted directly from each type of furnace is correlated with plant copper production capacity (Figure VI-2.2). Also, since dilution air is used in all instances to cool these furnace gases, Figure VI-2.3 estimates the quantity of dilution air required to provide specific stack temperatures. The sum of this dilution air and furnace gases will then give the estimated total stack gas flow rate as a function of plant production capacity.

Volumetric flow rate of exhaust gases from each of the pyrometallurgical smelting operations varies considerably with plant capacity. Examination of the figure shows variations in both the quantity and scatter of the data. However, data were only available for three (of the seven) plants having roasting facilities. The reverbatory furnace gas flow rates showed some wide scattering, with variations from the estimated least-squares line up to ± 100%. The converters showed less scatter to the exhaust rates than the reverbs, however, since several "blow cycles" comprise the operation of converters during a 24 hour day, the data in this figure represent daily average values. Typical undiluted gas flow rates are: roaster - 16,000 scfm; reverberatory - 50,000 scfm; converter - 16,000 scfm.

As stated earlier, dilution air is almost always used to cool the furnace exhaust gases in copper smelters. Figure VI-2.3 presents the volumetric flow rate of this dilution air per scfm of furnace gas versus final outlet or stack temperature. The curves in this figure were developed from heat balances utilizing reported values for furnace gas temperatures prior to air dilution. The average temperature of gases from roasters is approximately 1200° whereas converter gas temperature average 2200°F. Gases from reverberatory furnaces almost always pass through waste heat boilers prior to being diluted with air. The average temperature of the these gases after leaving the waste heat boiler and just prior to air dilution is approximately 700°F.

In order to estimate the total volumetric flow rate of exhaust gases from primary copper smelters, the following information must be known:

Plant copper production capacity in lb /hr.
Whether a roasting operation exists.
The percentage, if any, of the roaster and/or converter furnace gases that are sent to an associated acid plant

Assume for the purposes of illustration a smelter with an estimated daily copper production capacity of 200 tons (16,743 lb./hr.). Assume the facility has a roaster but does not have an associated sulfuric acid plant. Using plant No. 3 (Table VI-2.1) as an example, one can estimate the following flow rates of furnace gases from Figure VI-2.2:

Roaster:	15,100 scfm	
Reverberatory:	43,600 scfm	
Converter:	45,300 scfm	(3 x 15,100)
Sub Total	104,000 scfm	

Using a stack temperature of 550°F, the following quantities of dilution air can be obtained from Figure VI-2.3.

Roaster:	1.56 x 15,100 = 23,400 scfm
Reverberatory:	0.28 x 43,600 = 12,200 scfm
Converter:	3.62 x 45,300 = 164,000 scfm
Sub Total:	199,600 scfm

Adding this value to the volume of furnace gases gives a total volumetric flow rate of stack gases from this plant of 303,600 scfm. The actual measured scfm from plant No. 3 was 371,000 scfm.

GAS TEMPERATURE

Roaster and/or converter gases in some smelters may be in part or totally directed to sulfuric acid plants. Also, there may be a stack for the roasting and/or reverberatory furnace exhausts and an additional stack solely for converter exhausts. It is also very common to use a waste heat boiler with the reverbatory furnace gases. Temperatures of the 3 furnace gases prior to air dilution would be on the order of: roaster - 1200°F, reverbatory - 700°F and converter - 2200°F. The representative exhaust gas temperatures at these stacks are summarized for each of the 16 plants in Table VI-2.1. The data were obtained from the recent systems study of emissions from the nonferrous metals industry.[2] Although there is some scattering of the data presented in this table, 65% of the data (13 points) fall within the range of 300 to 400°F and 90% of the data (16 points) fall within 250 - 450°F. For dispersion calculations, 350°F should be used.

GAS VELOCITY

Stack gas velocities vary from plant to plant, but no data were found. Unless specific parameters are known, a velocity of 35 feet per second should be assumed.

STACK HEIGHT

It is common for one stack to handle the combined exhaust gases from more than one furnace, with stack heights usually in the range from 200 to 500 feet. This height would vary from plant to plant and unless an accurate estimate of height is available from the installation under investigation, an estimate of 300 feet should be used for this parameter.

TABLE VI-2.1

Exhaust Gases from Primary Copper Smelting Operations[2]

Plant No.	Estimated Capacity lb./hr.	Exhaust Gas Flow Rate*			Gas Temperature		
		Roaster scfm	Reverb scfm	Converter*** scfm each (avg)	Roaster °F	Reverb °F	Converter °F
1	16,577	9,500	28,400	2@ 19,250	250^1	250^1	450
2	21,158	-	40,500	3@ 13,917	-	315	300
3	16,743	16,800	53,600	3@ 13,201	-	600	550
4	6,164	-	26,200	3@ 5,683	-	300^1	300^1
5	23,990	139,000	83,200	4@ 23,507	390^1	390^1	350
6	35,819	24,600	155,000	2@ 32,250	-	-	-
7	18,409	-	40,500	3@ 14,462	-	350^1	350^1
8	23,824	-	53,700	4@ 25,500	-	350^1	350^1
9	19,159	-	51,100	3@ 8,662	-	400^1	400^1
10	32,820	11,000 (dryer)	79,100	3@ 21,824	350^1	350^1	350^1
11	10,829	-	45,500	4@ 18,323	-	350	350
12	25,157	-	46,500	2@ 16,450	-	450	650
13	3,832	N.R.	N.R.	-	900^1	900^1	900^1

*** Average for 24 hours; blow rates and time periods are available from the reference

1. Gas streams were combined and discharged through one stack.

TABLE VI-2.1

Exhaust Gases from Primary Copper Smelting Operations (Continued)

Plant No.	Estimated Capacity lb./hr.	Exhaust Gas Flow Rate* Roaster scfm	Exhaust Gas Flow Rate* Reverb scfm	Exhaust Gas Flow Rate* Converter*** scfm	Gas Temperature Roaster °F	Gas Temperature Reverb °F	Gas Temperature Converter °F
14	27,406	32,500**	33,500	1@ 111,000**	350^1	350^1	350^1
15	75,800	- -	165,000 79,400	59,850 58,200	-	350^1	350^1
16	21,908	N.R.	N.R.	-	-	-	-

** Includes Dilution Air

*** Average for 24 hours; blow rates and time periods are available from the reference

1. Gas streams were combined and discharged through one stack.

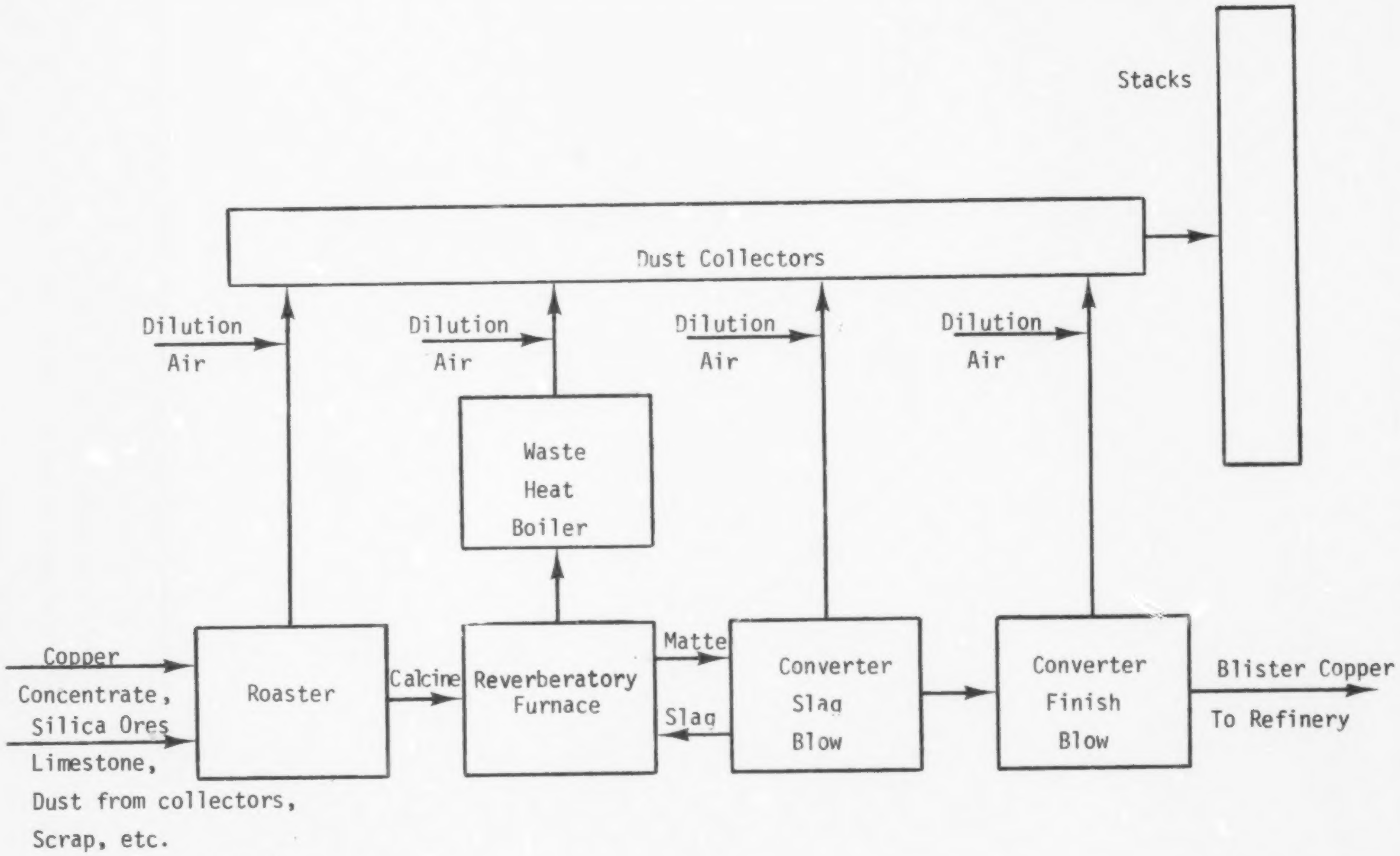
Stacks
Dust Collectors
Dilution
Air
Dilution
Air
Dilution
Air
Dilution
Air
Waste
Heat
Boiler
Copper
Concentrate,
Silica Ores
Limestone,
Dust from collectors,
Scrap, etc.
Roaster
Calcine
Reverberatory
Furnace
Matte
Slag
Converter
Slag
Blow
Converter
Finish
Blow
Blister Copper
To Refinery

Figure VI-2.1 Flow sheet of a typical primary copper smelter

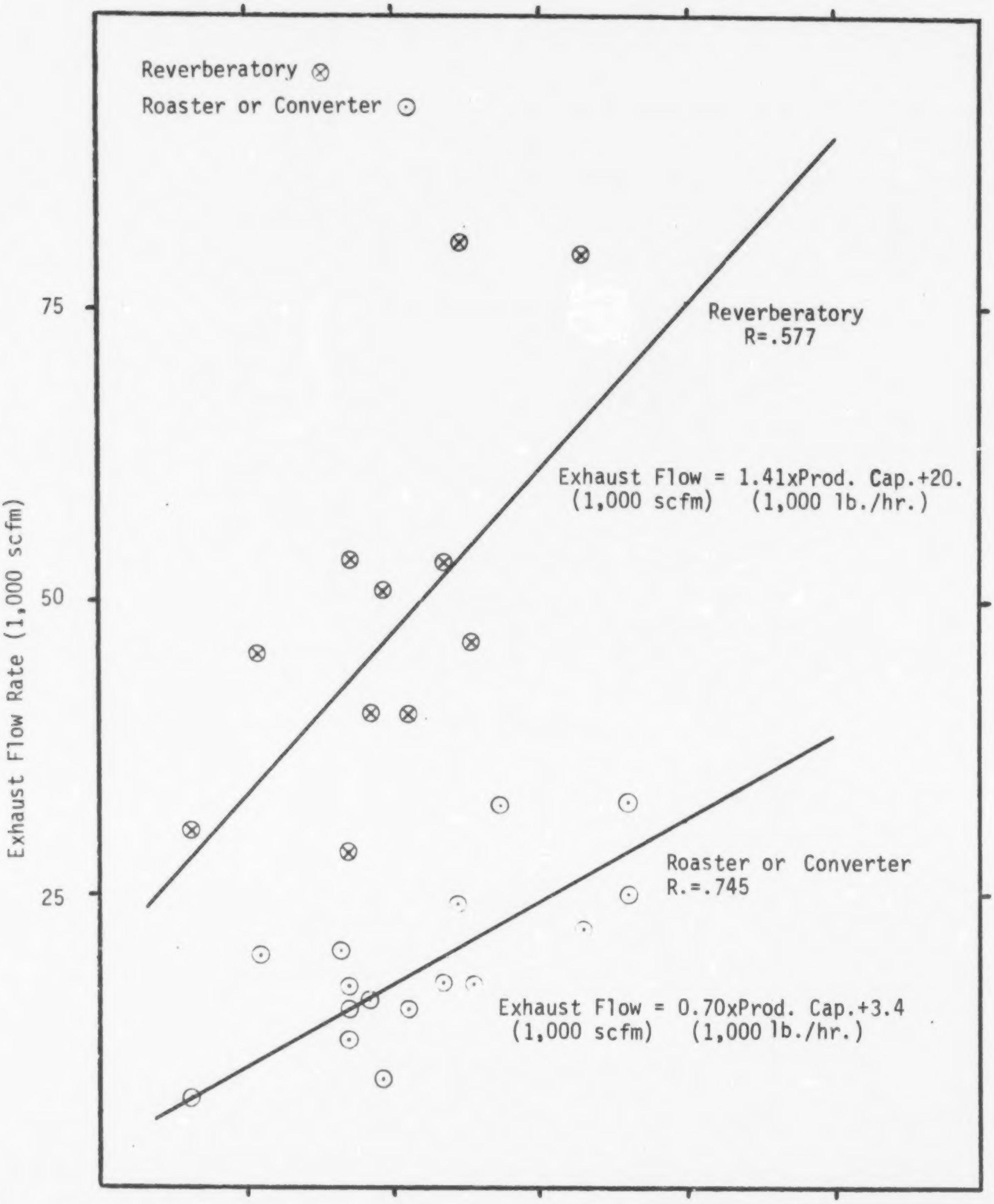

Figure VI-2.2 Exhaust flow rate of gases from copper smelter furnaces vs. production capacity.

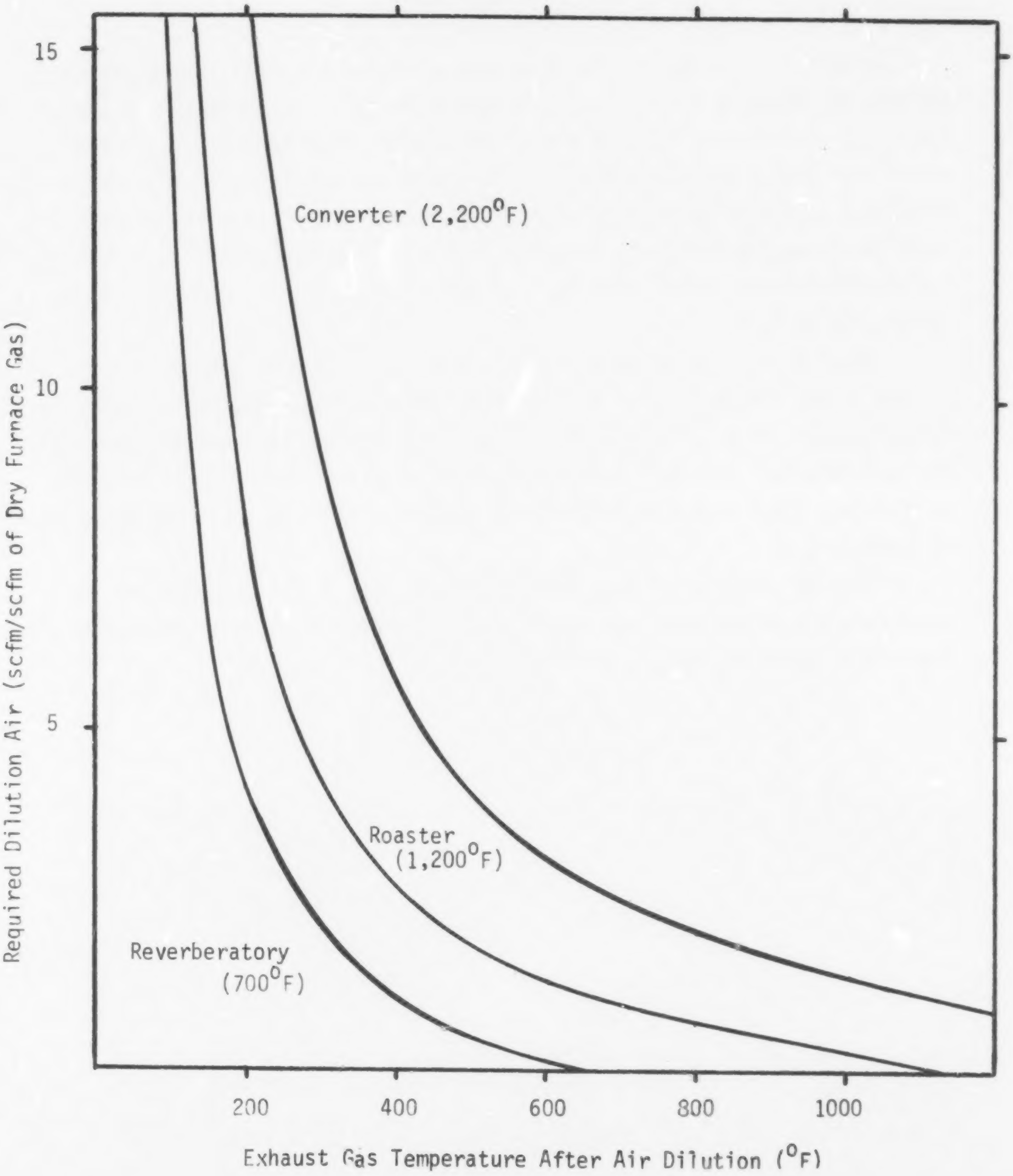

Figure VI-2.3 Volumetric flow rate of dilution air per scfm of furnace gas vs. stack temperature.

CHAPTER VI-3

IRON AND STEEL MILL [A]

Because of the complexity of an integrated steel mill, no attempt will be made to describe in detail the numerous process steps comprising the total facilities. However, each of the major iron or steelmaking stages will be considered individually in relation to the characteristics of the off gases exhausted into the atmosphere. The discussion will include sintering plants, blast furnaces, open hearth furnaces, basic oxygen furnaces, and electric furnaces. Exhaust gases from the manufacture of coke are discussed in a subsequent chapter.

Annual production of raw steel in the United States totals over 125 million tons. Major steel complexes are located around the Great Lakes with Pennsylvania, Ohio, Indiana, and Illinois accounting for over one-half of the Nation's steel production. Steel is produced in open hearth furnaces - 56 percent, basic oxygen furnaces - 34 percent, and electric arc furnaces - 10 percent.

Iron and steel mills are operated 7 days per week, 24 hours per day. Emissions are primarily iron oxide fumes. Control equipment includes cyclones, baghouses, precipitators, and scrubbers.

"Sintering Plant"

Originally, sintering was used as a means of recovering fines (flue dust) produced during the making of pig iron in blast furnaces. However, it is now recognized that low cost ore when combined with flux and sintered, can be converted into a useful and economical burden material for blast furnaces. Sintering machines accept and process a wide variety of feeds, differing from plant to plant and sometimes from week to week in each plant (Figure VI-3.1). The sintering machine is a long (100 feet) metal belt with oil or gas-fired burners underneath to heat the mix to the kindling temperature. Plants range from 2,000 to 6,000 tons/day capacity (150,000 to 500,000 lb./hr.).

GAS FLOW RATE

It has been reported that a typical sintering machine produces approximately 1.5 - 2 scfm of gases per lb./hr. of sinter (130 - 170 scfm at 70°F per ton/day of sinter).[4] Since these gases leave the sintering machine at temperatures generally at or below 400°F, additional cooling with dilution air and/or water sprays is not required.

In addition to the gases from the sintering machine, the hot sinter is fed to a sinter cooler where additional gases are exhausted. Reported data indicate that an additional 0.2 - 0.25 scfm per lb./hr. of sinter capacity is exhausted at this stage.[4] The total stack gas flow rate from sinter plants can, therefore, be expected to range from 1.7 - 2.3 scfm per lb./hr. of sinter produced.

GAS TEMPERATURE

The temperature of exhaust gases entering the control systems has been reported to range from 100 to 400°F. Scrubbing systems will cool gases to 100 to 150°F, whereas temperature of gases from sintering machines to mechanical separators, baghouses and electrostatic precipitators is somewhat higher, 175 to 400°F.

GAS VELOCITY

No data were available, but gas exit velocities are expected to range from 25 - 50 feet per second depending upon plant operating conditions.

STACK HEIGHT

Stack heights for sintering operations range between 150 and 200 feet.

"Blast Furnaces"

The first step in the conversion of iron ore into steel takes place in the blast furnace. It is a large steel cylindrical structure approximately 100 feet high lined with fire brick. Iron ore, coke, and limestone are fed in the top and heated air is blasted in through the bottom. Between 100 and 300 tons of molten iron and slag are drawn off every few hours and taken to open hearth or other steel making furnaces. (Figure VI-3.2)

Exhaust gases which are rich in carbon monoxide are burned to heat stoves, coke ovens, or generate steam; such gases are not normally vented directly to the atmosphere.

GAS FLOW RATE

Gases leave the blast furnace at temperatures of 350 - 540°F and at flow rates of about 0.5 - 0.8 scfm per lb./hr. of pig iron produced (110,000 - 150,000 actual cubic feet per ton of pig iron). In other units, about 6 tons of gases are produced per ton of pig iron produced. Actual flow rate is a function of the coke rate as shown in Figure VI-3.3. Gases emitted from blast furnaces are cleaned in the following three steps with the first two used almost universally throughout the industry:

- Preliminary cleaning - settling chambers or dry type cyclones.
- Primary cleaning - gas washers or wet scrubbers.
- Secondary washing - electrostatic precipitators or high energy scrubbers.

Approximately 25% of the blast furnace gases are used as a fuel for the blast stoves which preheat the air to the blast furnaces. The resulting combustion products of the blast stoves range from 1.2 - 2.8 lbs. of combustion gas per lb. of pig iron. Assuming a density of 0.08 lb./cu. ft. at 60°F, the volumetric flow rate of combustion products will range from 0.25 - 0.58 scfm per lb./hr. of pig iron.

GAS TEMPERATURE

Combustion gases from the blast stoves are ducted to a common chimney although separate chimney installations still exist. The temperature of these blast stove combustion gases prior to mixing with other gases is unknown, but 500°F may be assumed. The same exit temperature would be expected for the blast furnace gas used to heat coke or generate steam.

GAS VELOCITY

No data were available,but stack effluent exit velocities will vary from stack to stack on any given plant site. Normal design criteria would place this parameter in the 25 - 50 fps range.

STACK HEIGHT

No data were available, but stack heights for blast furnace operations will undoubtedly be as high or higher than the blast furnaces themselves. Therefore, assume 150 feet when no data are available.

"OPEN HEARTH FURNACE"

Ten years ago open hearth furnaces produced 90% of the Nation's steel. Today only about one-half of the total is produced by open hearth furnaces since basic oxygen furnaces can now produce more steel more quickly and more economically. The open hearth furnace typically holds between 100 and 200 tons of steel and completes one heat cycle in about 12 hours. A flow diagram from a typical open hearth and electric furnace shop is shown in Figure VI-3.4.

Flame from combustion of oil, gas, tar, coke, oven gas, etc. travels the length of the furnace above the molten metal. Upon leaving the furnace exhaust gases pass through a checkerwork then possibly through a waste heat boiler to control equipment.

Oxygen lancing is utilized to shorten the heat time, and particulate emission rates and gas volumes are both increased considerably. Oxygen consumption ranges from 600 to 1000 cubic feet per ton (900 to 1,667 scfm during the oxygen lancing).

GAS FLOW RATE

For the open hearth furnaces installations surveyed, exhaust gas flow rates ranged from 10,000 to 73,500 scfm (Table VI-3.1). These data were plotted in Figure VI-3.5 to give an equation which may be used in estimating exhaust flow rates from various size installations. If the installation utilized oxygen lancing, an additonal 1000 scfm should be added to the value obtained from Figure VI-3.5.

GAS TEMPERATURE

The temperature of the combustion gases leaving the furnace range from 460 - 1800°F (Table VI-3.1). These gases must be cooled before entering air pollution control equipment. This is usually accomplished through the use of waste heat boilers which cool the gases to 500 - 600°F. Exit temperatures from control equipment are expected to be about 200°F.

GAS VELOCITY

No data were available, but 25 - 50 feet per second may be assumed in detailed calculations.

STACK HEIGHT

Stack height will vary from plant to plant, but observations at several steel mills indicate a range between 150 and 200 feet in height. Assume 200 feet when no data are available.

"Basic Oxygen Furnace"

The basic oxygen furnace (BOF) is a top blown converter with a capacity of 50 to 325 tons of steel. Oxygen is blown at rates of 20,000 scfm onto the surface of the molten metal resulting in violent agitation and mixing of the molten pig iron and oxygen. The heat cycle for a basic oxygen furnace will be about 1 hour or less. All basic oxygen furnaces in this country have been built within the past 15 years, and all are equipped with control equipment, either high energy scrubbers or electrostatic precipitators.

Combustion gases leave the furnace mouth at approximately 2900°F with the following gas composition:

CO	:	74.0 - 90.5%
CO_2	:	5.0 - 16.0%
N_2	:	3.0 - 8.0%

At the interface of the furnace mouth and ventilation hood, controlled quantities of dilution air combine with the furnace gases. In the conventional BOF process, 100-150 percent excess air is utilized to oxidize all but trace quantities of carbon monoxide.

GAS FLOW RATE

Figure VI-3.6 may be used to estimate exhaust flow rates from BOF furnaces. If water sprays are used to cool the gases after passing through a waste heat boiler, Figure VI-3.7 may be used to estimate the volume of water vapor added to the stack before exiting to the atmosphere.

GAS TEMPERATURE

The temperature of exhaust gases from the basic oxygen furnace range from 2700 - 3100°F. The gases are then cooled by air dilution or water sprays, and in some instances, waste heat boilers, prior to passing through electrostatic precipitators and/or high energy scrubbers and out the stack. The final temperature of the gases at the stack outlet are generally around 300°F.

GAS VELOCITY

No data were available, but stack gas exit velocity from the BOF process is estimated at 25 - 50 fps.

STACK HEIGHT

No data were available, but stack heights normally associated with the BOF steelmaking process are expected to range from 150 - 250 feet with an average of approximately 200 feet.

"Electric Arc Furnace"

Electric furnaces are used primarily for production of special alloy steels. The furnaces are refractory lined cylindrical vessels with large carbon electrodes passing through the furnace roof. They produce from 2 to 200 tons of steel per heat. Oxygen may be used to increase the production rate.

The off gases from electric arc furnace are generally collected by one of three techniques: use of hoods over and around the furnace points of emission, direct extraction of gases from the furnace interior, or extraction of gases from the building roof. Baghouses and wet scrubbers are the primary techniques for dust control. Cooling of the exhaust gases is accomplished by radiation-convection cooling columns, by water-spray nozzles or by dilution air.

GAS FLOW RATE

Table VI-3.2 presents furnace data on exhaust gas characteristics from electric arc steel furnaces. These data were plotted in Figure VI-3.8 which may be used to estimate exhaust flow rates from electric are furnaces.

GAS TEMPERATURE

The temperature data from Table VI-3.2 indicate that stack temperatures following cooling and dust collection will range from about 75 to 150°F. An average temperature of about 150°F should be assumed when no data are available.

GAS VELOCITY

No data were abailable, but stack gas velocities in the range of 25 - 50 feet per second are expected.

STACK HEIGHT

As in other steelmaking processes, the stack height will vary from plant to plant; however, a range of 150 - 250 feet is normally found with this process.

TABLE VI-3.1

Exhaust Gases From Open Hearth Furnaces

Tons/heat	Capacity tons/hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Reference
300	37.5	60.0	1400-1800	19
550	50.0	66.5	550	20
600	55.0	73.5	550	20
360	45.0	70.0	600-1500	21
63	6.0	14.9	460	22
60	5.5	14.4		23
110	10.0	20.0		23
205	25.5	40.0		23
225	19.0	33.0		23
250	21.0	10.0 - 32.0	550	23
275	23.0	18.0 - 33.0	550	23
330	41.0	37.7		23
4-220	27.5	71.0	600	24
175	14.5	35.0		25
U.S. Avg: 175	17.5	35.0		23

TABLE VI-3.2

Exhaust Gases From Electric Arc Furnaces[7]

Furnace Capacity tons/heat	Exhaust Flow scfm	Exhaust Flow cfm/ton	Exhaust Temp. °F	Melt Time hrs./heat	Control Equipment
25, 8, 2		2,140		6.5,3.5,3	Baghouse
17	40,600	2,610	137	2	Baghouse
14	31,700	4,280	139	2.5	Baghouse
19	46,100	3,160	153	2.5	Baghouse
.75,4.5,4.5,4.5		2,370		2,2,2,2	Baghouse
4,4	14,110	2,760	121	2,2	Baghouse
3.5	9,900	3,940	106	1.5	Baghouse
3.3, 3.3		1,200		2,2	Baghouse
65.0[24]	38,250		550		
65.0[24]	38,250		550		
80.0[24]	54,100		480		
150.0[26]	132,000		275		
50, 75, 75[23]	98,000 total		127		
1, 3, 6, 6[23]	46,000 total		124		
6[23]	14,500		130-180		
3[23]	11,000		142		

TABLE VI-3.2

Exhaust Gases From Electric Arc Furnaces[7]

Furnace Capacity tons/heat	Exhaust Flow scfm	Exhaust Flow cfm/ton	Exhaust Temp. °F	Melt Time hrs./heat	Control Equipment
6, 20[22]	20,600 total		89		Wet Scrubber
20[22]	24,600		76		Wet Scrubber
6[22]	20,700		92		Wet Scrubber
3, 3[22]	10,860 total		92.5		Wet Scrubber
50[22]	29,800		99		Wet Scrubber
75[22]	35,600		105		Wet Scrubber

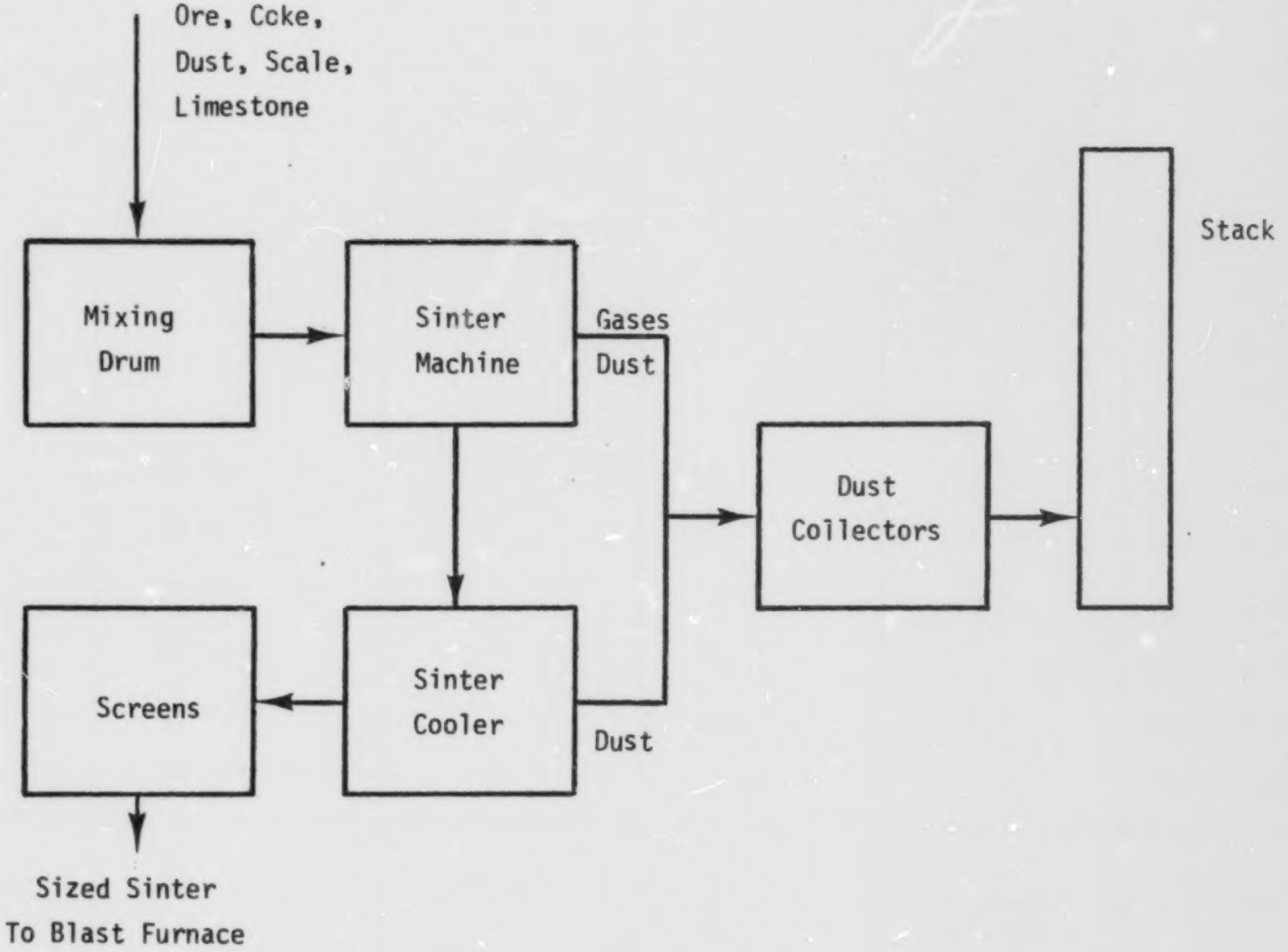
Ore, Ccke,
Dust, Scale,
Limestone
Mixing Drum
Sinter Machine
Gases
Dust
Dust Collectors
Stack
Sinter Cooler
Dust
Screens
Sized Sinter
To Blast Furnace

Figure VI-3.1 Flow sheet for a sintering plant

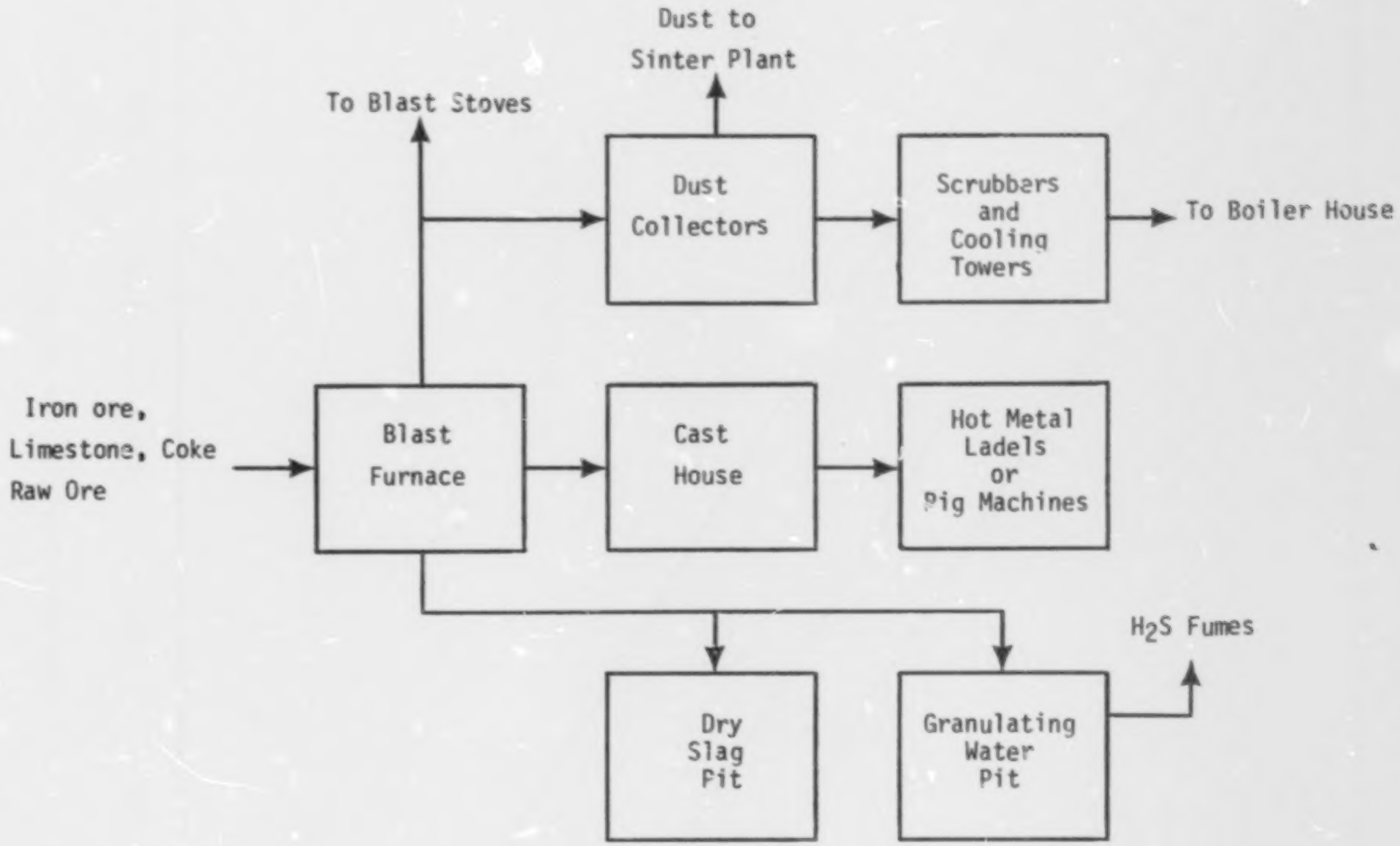
Dust to
Sinter Plant
To Blast Stoves
Dust Collectors
Scrubbers and Cooling Towers
To Boiler House
Iron ore, Limestone, Coke Raw Ore
Blast Furnace
Cast House
Hot Metal Ladels or Pig Machines
H_2S Fumes
Dry Slag Pit
Granulating Water Pit

Figure VI-3.2 Flow diagram of blast furnace operations

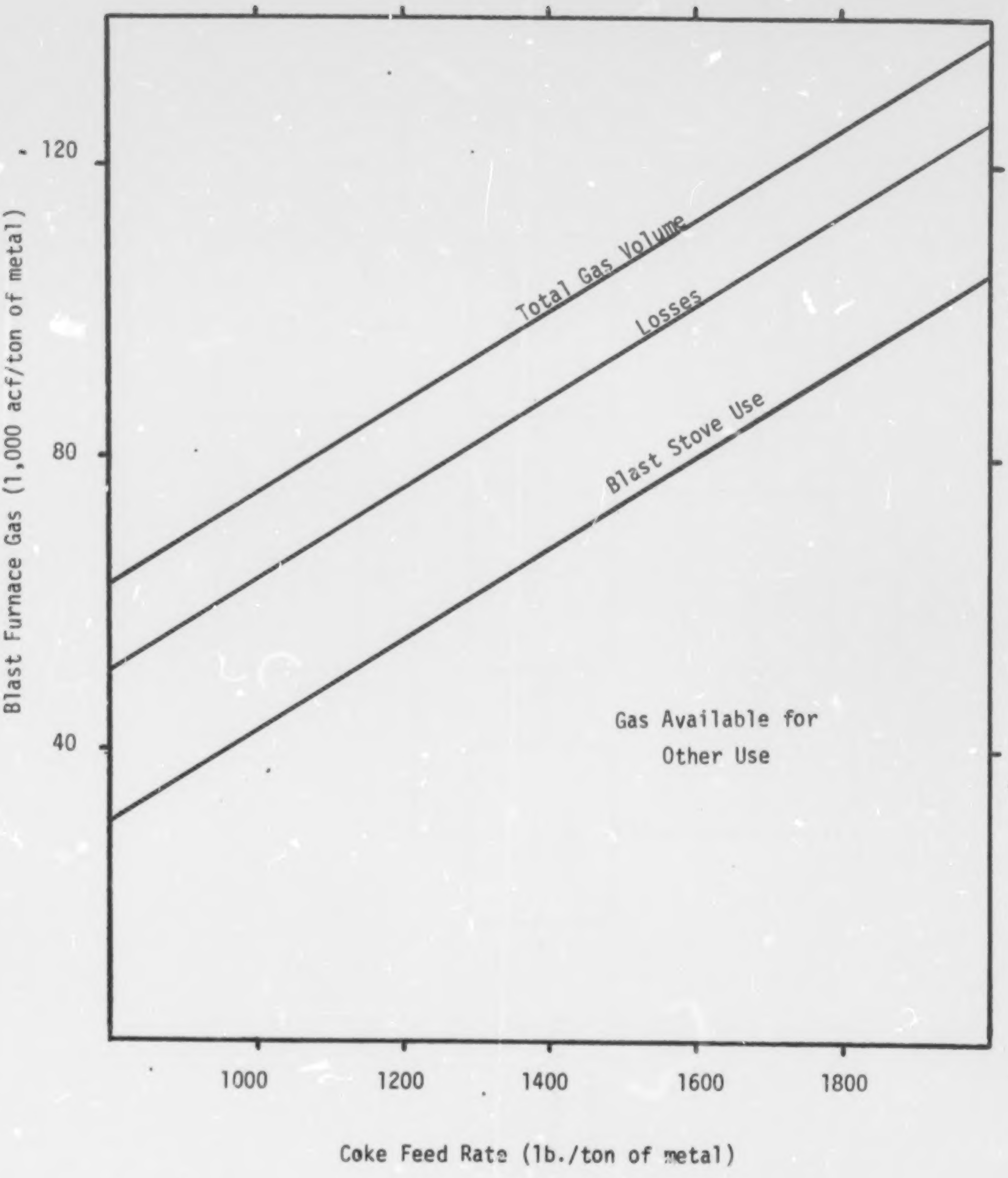

Figure VI-3.3 Effects of coke feed rate on volume of blast furnace gas[4]

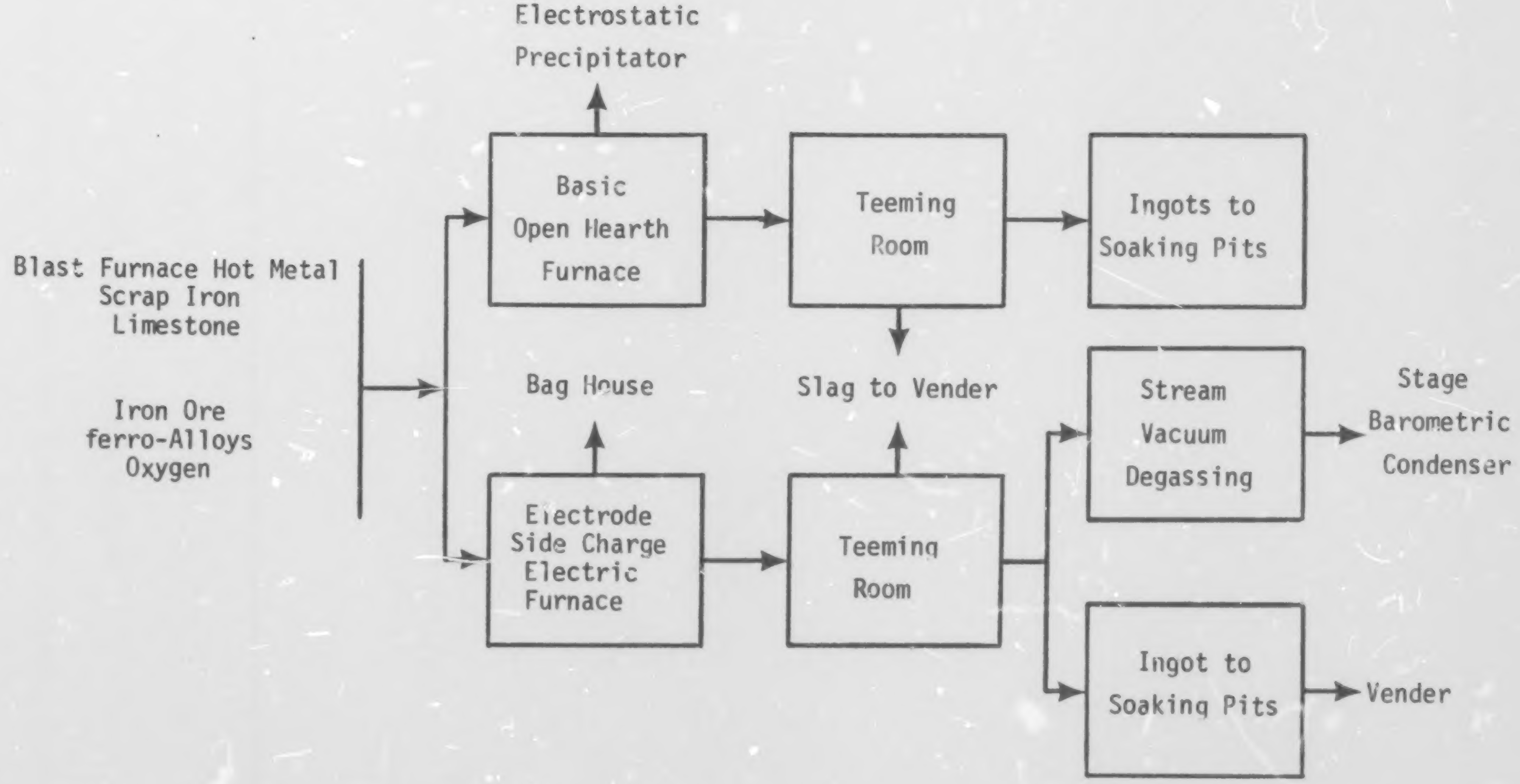
Blast Furnace Hot Metal
Scrap Iron
Limestone
Iron Ore
ferro-Alloys
Oxygen
Electrostatic
Precipitator
Basic
Open Hearth
Furnace
Bag House
Electrode
Side Charge
Electric
Furnace
Teeming
Room
Slag to Vender
Teeming
Room
Ingots to
Soaking Pits
Stream
Vacuum
Degassing
Stage
Barometric
Condenser
Ingot to
Soaking Pits
Vender

Figure VI-3.4 Flow diagram for open hearth and electric furnace shop.

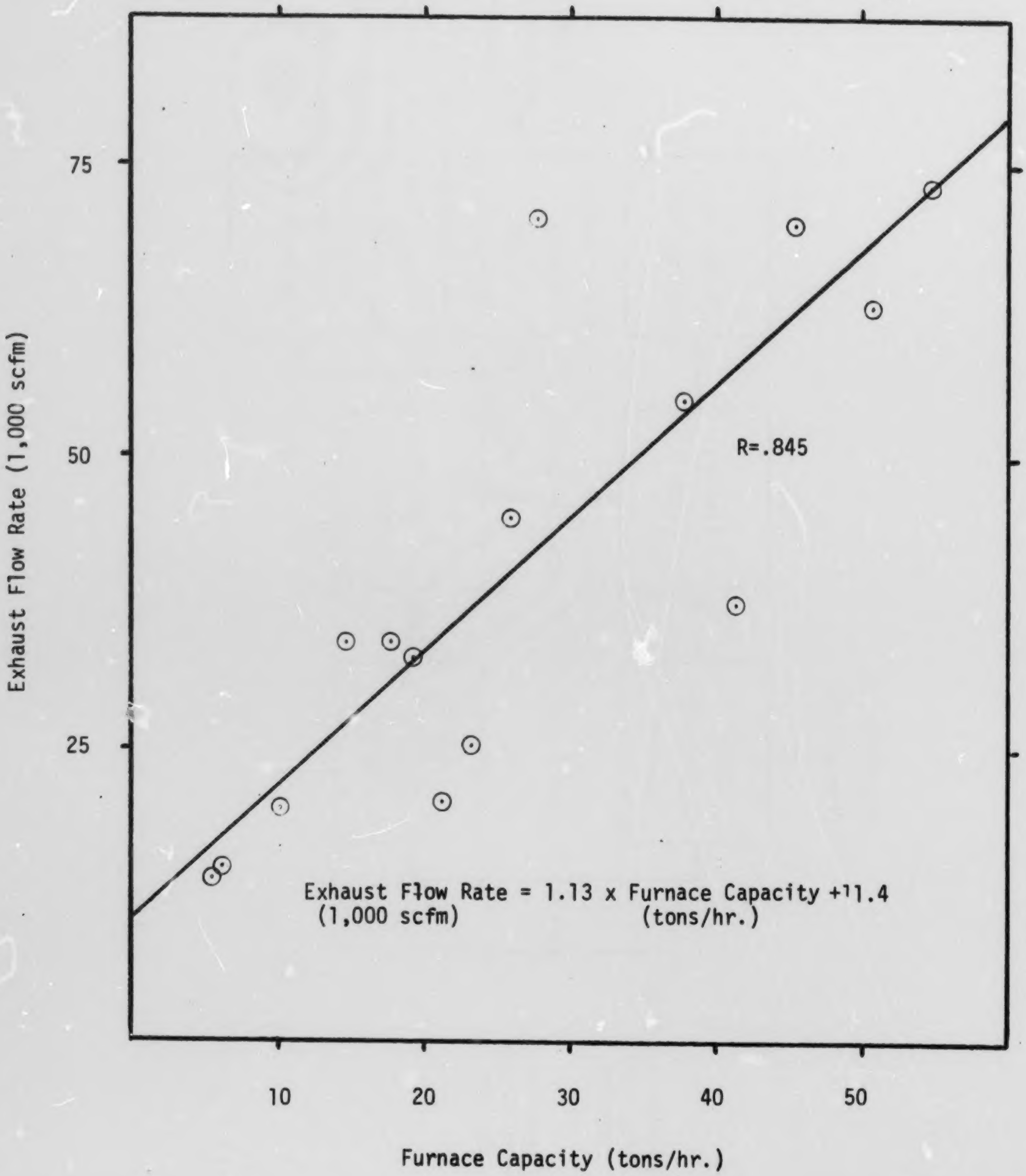

Figure VI-3.5 Exhaust Flow rates for various size open hearth furnace

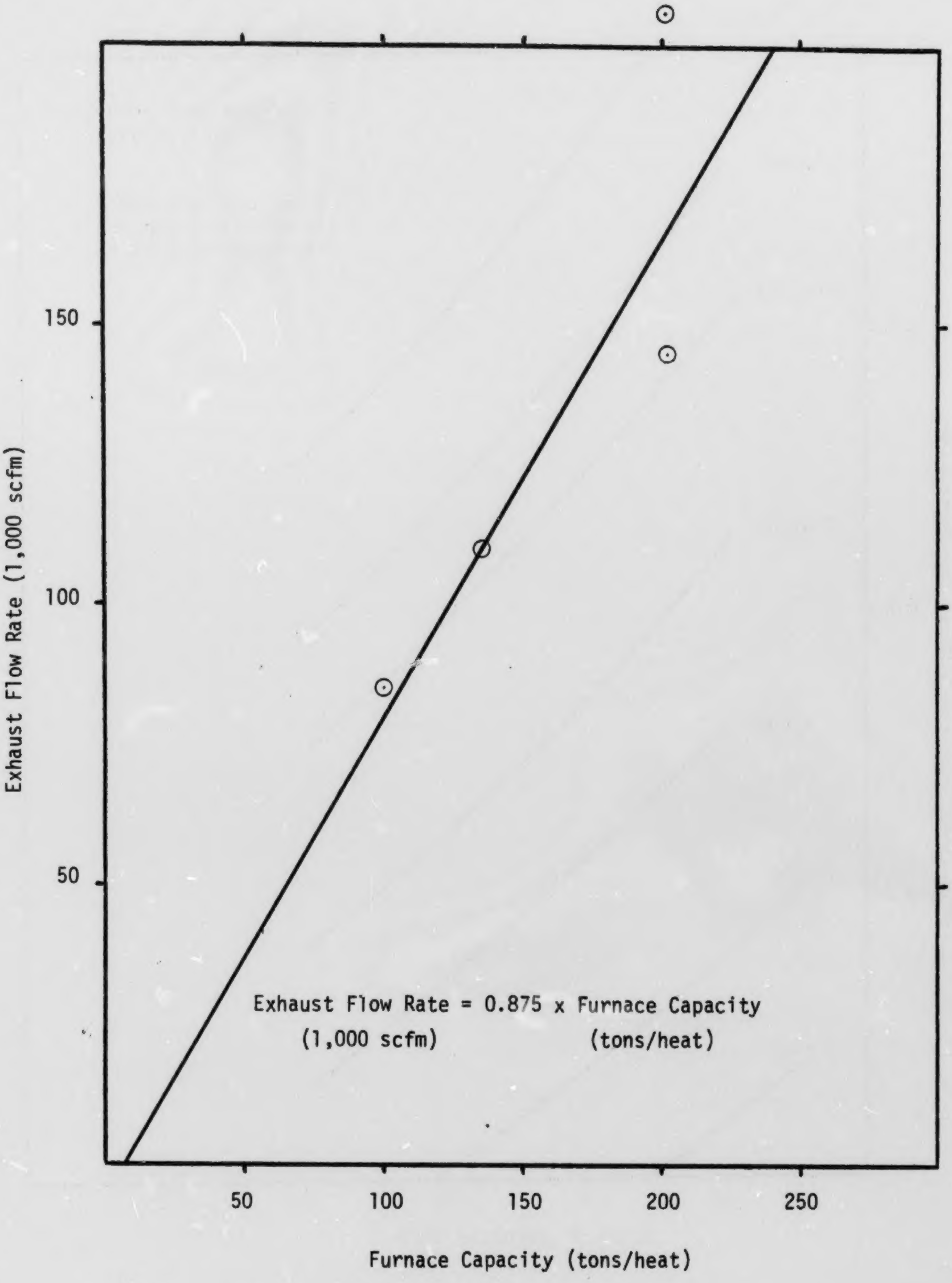

Figure VI-3.6 Exhaust flow rates from BOF furnaces.

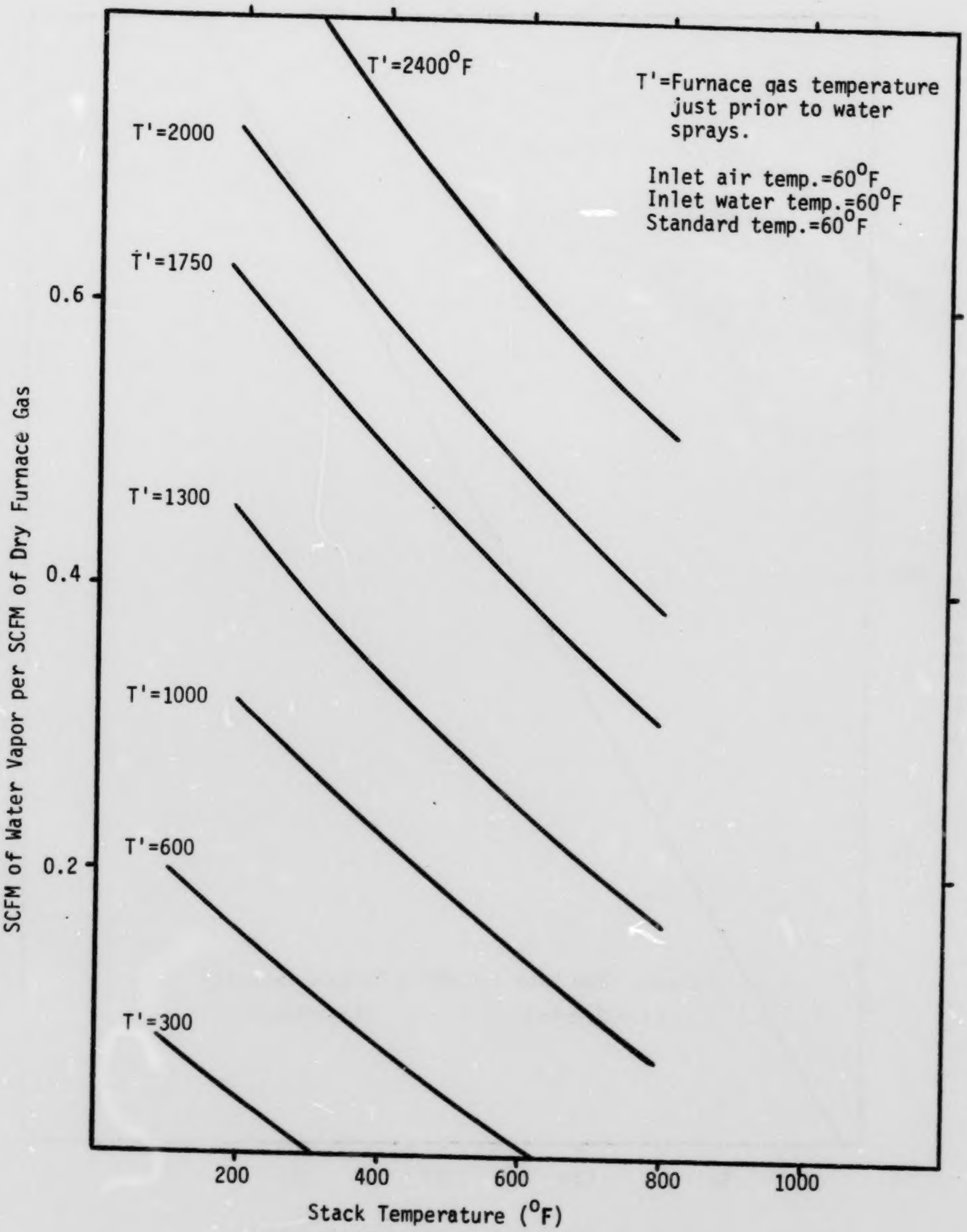

Figure VI-3.7 Volumetric flow rate of water vapor per scfm of furnace gases vs. stack temperatures.

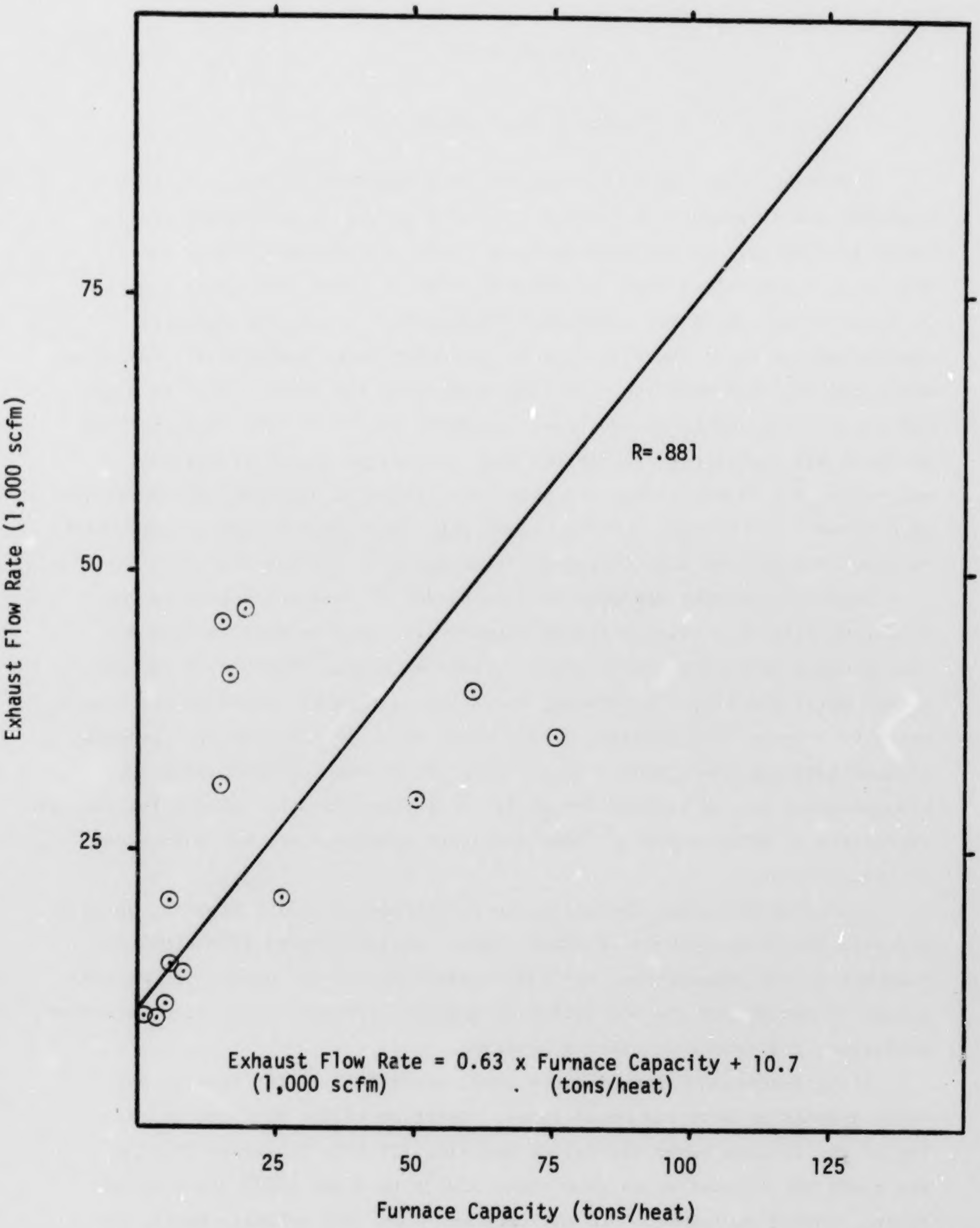

Figure VI-3.8 Exhaust Flow rates for various size electric arc furnaces

CHAPTER VI-4

PRIMARY LEAD SMELTER [B]

Currently there are only 8 primary lead smelters in the U. S. with a combined annual production capacity of about 830,000 tons. Three are located in Missouri and one each in Texas, Utah, California, Idaho, and Montana. Primary lead smelters are generally operated seven days a week, 24 hours a day except for occasional repairs or closings due to market conditions. Five of the eight plants in recent years operated 365 days/year, while one operated only 260. Average production for these plants is about 100,000 tons/yr. which is equivalent to about 25,000 lb./hr. Primary lead smelters all employ essentially the same processing steps; sintering, reduction in a blast furnace and refining. Refining also includes operation of a dross reverberatory furnace. In addition lead smelter operations include cadmium recovery and slag fuming for zinc recovery (Figure VI-4.1).

Lead sulfide ores are converted to oxides of lead and sulfur in the sintering step at a relatively low temperature. The oxidized solids are then reduced with coke in the blast furnace at a high temperature to form impure metal and slag. A refining operation is then performed on the impure metal to produce lead bullion, 95-99% pure, which is the principal product of lead smelting operations. Secondary products such as zinc oxide and cadmium dusts may be refined for market or shipped to other plants for further extraction of other metals. These auxiliary processes are not considered in this chapter.

Sintering off gases include large quantities of sulfur dioxide, up to 5 percent, and trace amounts of other gases. Organic vapors from flotation reagents in the concentrates are also present in the off gases. Fumes contained in the off gas include oxides of arsenic, cadmium, lead, zinc, selenium, tellurium, and traces of other substances.

Blast furnace off gases include small amounts of sulfur dioxide and large amounts of dust and metal fumes. Dilution of the flue gas at the top of the furnace burns the carbon monoxide (25-50%) to carbon dioxide and cools the exhaust gases from about 1200°F to about 400°F prior to entering control equipment. In the refinery step, the refinery kettle and dross furnace generate metal fumes. The dross furnace operates 20 to 70 percent of the time the refinery furnace operates.

Sinter gases at two or three of the eight plants are sent to a sulfuric acid recovery plant. Electrostatic precipitators or baghouses are used to collect dust and fumes from the entire plant's exhaust gases.

GAS FLOW RATE

Actual plant data from 5 plants[2] indicate that total stack exhaust gases from the sintering, blast furnace and refining steps range from 4.43 - 16.92 scfm per lb./hr. of plant production capacity with an average of about 10 scfm per lb./hr.

The volume of gases emitted from each of the major sources (i.e. sintering machines, blast furnaces, refinery kettles and dross reverberatory furnaces) obviously is dependent primarily on machine or furnace size and material throughput. However, such data were not available, so correlations of gas flow rates were made with total plant production. In general gas volumes from the sintering machine run about 100 - 200 scfm per sq. ft. of bed area. Temperatures normally range between 250 - 600°F. Blast furnace gas is related to size but generally runs 5,000 - 9,000 scfm. Off gases from the dross reverb run from 1,000 - 3,000 scfm and exit at a temperature of about 1,400 - 1,800°F.

Only three data points were available showing volume of exhausts emitted from sintering machines at different plant capacities (Table VI-4.1). Flow rates ranged from 0.80 - 1.40 scfm per lb./hr. of lead production for plant capacities of 27,000 to 46,000 lbs./hr. (Figure VI-4.2). As a rule of thumb, gas volumes run about 100 - 200 scfm per sq. ft.

Significant quantities of dilution air enter the blast furnace exhausts either through charging ports or at the top of the furnace. As mentioned earlier, this air is necessary to burn the CO present in the furnace gases. Five data points were available (Figure VI-4.2) with which to draw a least-squares line. The average flow of gases from blast furnaces at the stack would be 0.6 scfm per lb./hr. of plant capacity. Since the data were quite scattered the deviations between the data and the least squares line are significant.

Volumetric flow rates of gases from dross reverberatory furnaces are significantly less (slope of least squares line is 0.3 scfm per lb./hr.) than the gases from blast furnaces for the same plant capacity (Figure VI-4.2).

No data were reported for exhaust gas volumes from the refining kettles, but some idea of the volume could be estimated by subtracting the other stack gases, after dilution, from the total given in Table VI-4.1. Assume 500°F for the sinter gases and 1800°F each for the blast furnace and dross reverberatory gases.

GAS TEMPERATURE

Limited stack gas temperature data were available for the 8 primary lead smelters. Temperatures of the cooled gases at the stack ranged from 110 to 300°F, with sintering stack temperatures somewhat lower (135°F) than stack gases from the furnace and refining operations (225°F). For dispersion calculations 200°F should be assumed for all effluents.

GAS VELOCITY

No data were available, but stack gas exit velocity will vary from plant to plant and within a plant. It is expected to range from 25 - 50 feet per second. If exit velocity information is not available, a velocity of 35 feet per second can be assumed.

STACK HEIGHT

No data were available, but the major stack at one plant was observed to be about 200 feet in height. Stack heights will vary from plant to plant,[2] however when actual stack information is not available, a height of 200 feet may be assumed.

TABLE VI-4.1

Exhaust Gases From Primary Lead Smelters[2]

Plant #	CAPACITY		EXHAUST GAS FLOW RATE (scfm)				
	Tons/Yr.	Lb/Hr	Sintering	Blast Furnace	Refining Kettles	Dross Reverb.	Total Plant
1	76,000	17,326	8,667 (1st Stage Only)	8,985	N.R.	1,163	--
2	122,000	29,238	34,247	11,733	N.R.	8,985	276,934
3	198,000	45,815	35,938	27,693	N.R.	N.R.	202,733
4	120,000	27,406	37,523	24,628	N.R.	N.R.	111,725[1] 133,182[2]
5	91,000	20,742	N.R.	21,562	N.R.	N.R.	198,716
6	42,000	13,495	N.R.	N.R.	N.R.	6,342	127,897[1] 100,415[2]
7	100,000	22,824					
8	80,000	18,243					

N.R. Not Recorded

[1] Sintering machine stack

[2] Blast furnace, refining kettle and dross reverberatory served by a common stack.

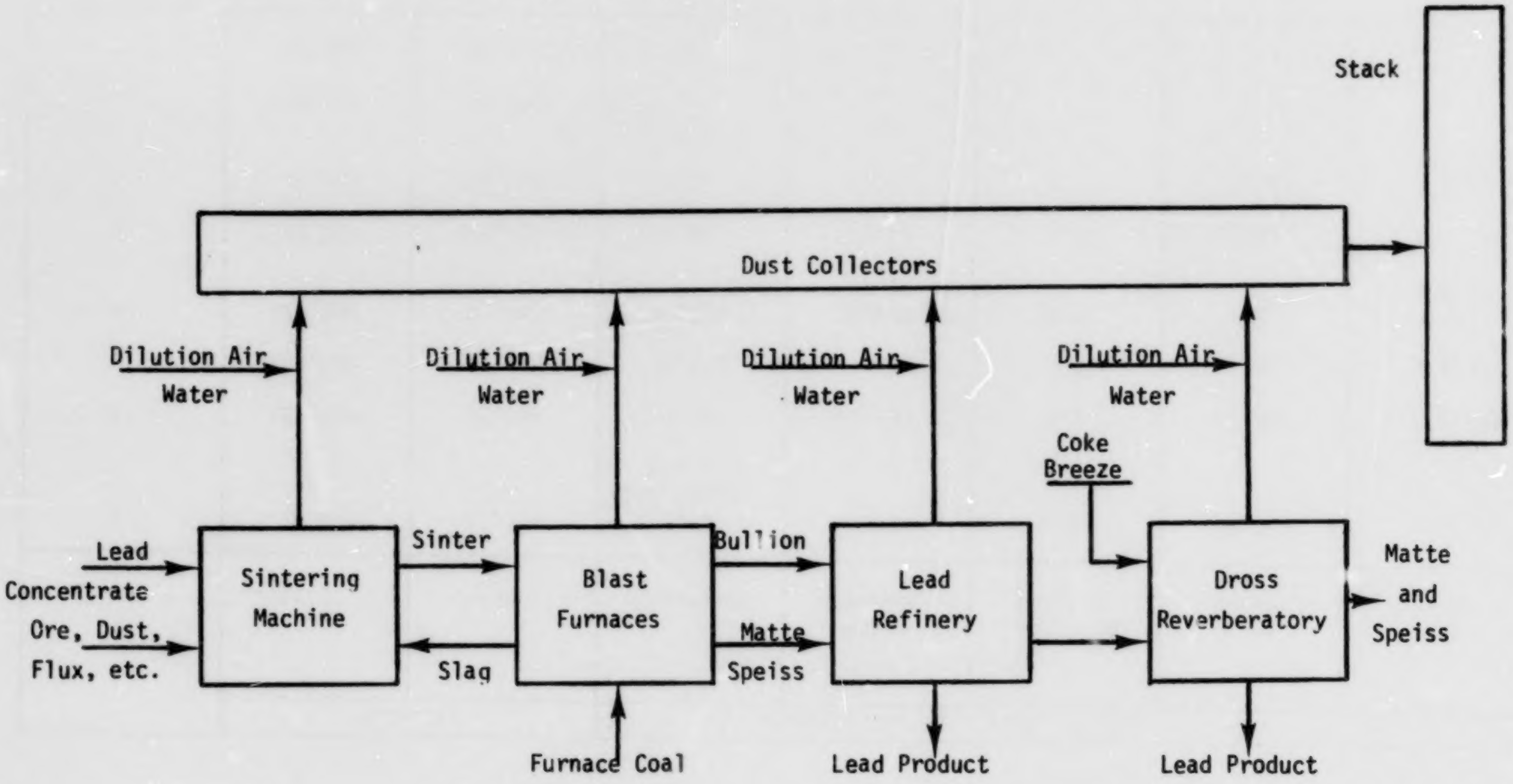
Stack
Dust Collectors
Dilution Air
Water
Dilution Air
Water
Dilution Air
Water
Dilution Air
Water
Coke Breeze
Lead Concentrate
Ore, Dust, Flux, etc.
Sintering Machine
Sinter
Slag
Blast Furnaces
Furnace Coal
Bullion
Matte Speiss
Lead Refinery
Lead Product
Dross Reverberatory
Matte and Speiss
Lead Product

Figure VI-4.1 Flow diagram of primary lead smelters

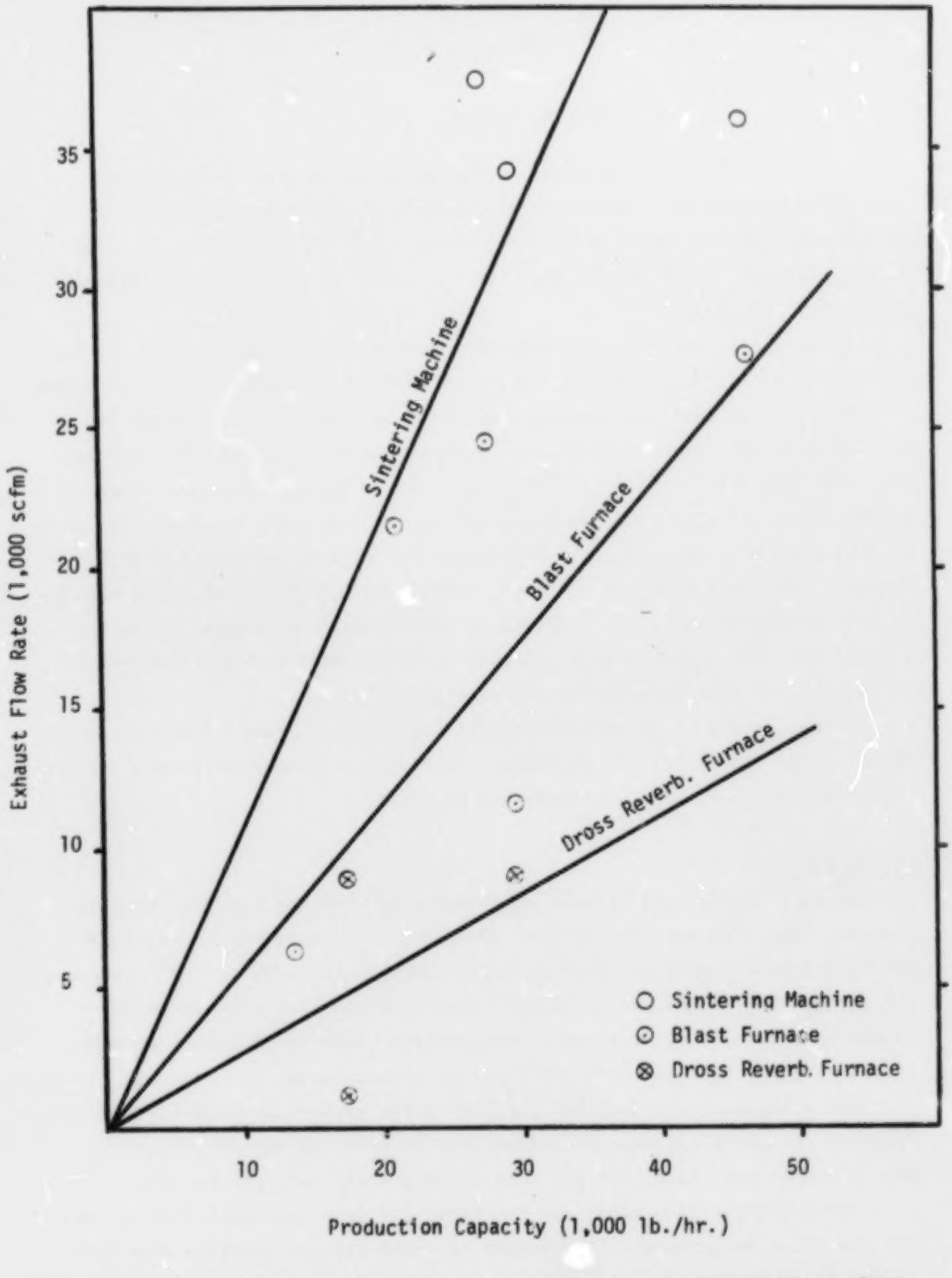

Figure VI-4.2 Exhaust flow rates from the lead sintering machine, blast furnace and dross reverberatory furnace as a function of plant production capability

CHAPTER VI-5

PRIMARY ZINC SMELTER [C]

There are currently 14 primary zinc smelters in the United States, located in seven states: Pennsylvania-2; West Virginia-1; Illinois-2; Oklahoma-3; Texas-3; Montana-2; and Idaho-1. Typical plant size is about 90,000 tons/year or 25,000 lb./hr. but the range is from 44,000 tons/year to 252,000 tons/year.

Primary zinc smelters are generally operated seven days a week, 24 hours a day, except for occasional scheduled or unscheduled shutdowns. Extraction of zinc requires that the raw material first be processed to convert the zinc content to a dense zinc oxide. Roasting, sintering and calcining are the three extraction operations that are used to accomplish this. Some plants roast (12 plants); some roast and sinter; one only sinters. Calcining is performed only on oxide ores or on material previously oxidized by a roaster. The zinc metal is extracted from the preprocessed material either by heat reduction with fuel followed by distillation (9 plants) or by dissolving the zinc oxide in acid and precipitating the metal electrolytically (5 plants). A flow diagram appears as Figure VI-5.1.

Emissions from zinc smelters consist of sulfur dioxide, dust, and metal fumes. Nine plants recover SO_2 with acid plants. Particulates are collected by flues, cyclones, precipitators, and baghouses.

GAS FLOW RATE

Roaster exhaust gas volumes vary primarily with the type and size of roaster. The Rapp roasters produce 20-35,000 scfm at temperatures of 730 - 900°F; multiple hearth roasters generate about 15,000 scfm at 500°F entering the precipitator (includes dilution); suspension roasters produce 10,000 - 15,000 scfm at 600° after a waste heat boiler; fluid bed roasters produce 11,000 - 18,000 scfm at about 500°F at the precipitator.

Sintering machines vary the gas flow rates depending on feed. With a calcined feed, exit gas rates are from 140-240 scfm per sq. ft. of grate. With a concentrate feed, the gas rate is only 18-20 scfm per sq. ft.

Calcining gas flow rates are not known and data were available on only two distillation furnaces. The volume of gases emitted directly from each of the three primary sources (i.e., roasters, sinter machines and distillation furnaces) is correlated with plant zinc production. Since both dilution air and water sprays are used for cooling furnace gases, data presented for copper smelters can be utilized to estimate the quantity of dilution air and water required to produce a certain stack temperature. By knowing or estimating the degree of cooling associated with each method, dilution air and/or water vapor can be summed with furnace gases to estimate the total stack gas flow rates as a function of plant production capacity.

Figure VI-5.2 relates the volumetric flow rate of exhaust gases from the roasting and sintering furnaces respectively, as a function of plant capacity.[2] Based upon the data available, straight line correlations exist for all but a few data points. No explanation was found for the wide variations of these few points, and so for the purpose of this study, they were neglected.

The one source of data found for volumetric flow rates from distillation retort furnaces[8] indicated that approximately 20-30 scfm of exhaust gases would be generated per lb./hr. of zinc produced. These values suggest that large volumes of dilution air mix with the gases generated in the distillation furnace after they leave the condenser.

GAS TEMPERATURE

Operating temperatures for zinc roasters vary between 1200 and 1900°F. Since fluid bed and suspension roasters are most commonly used and since operating temperatures for these units generally ranged from 1700 to 1800°F, an outlet temperature (T') for roasters of 1750°F should be selected. Sintering machine exit gases usually range from 500 - 700°F and so an average temperature (T') of 600°F should be selected.

Gas temperatures at the stack exit were available for 8 of the 14 primary zinc smelters. The cooled exit gases ranged in temperature from 130 to 400°F. Gases from the roaster and calciner were cooled to 300 to 400°F whereas gases from the sintering machine were cooled to 200°F.

Although there is no available data for stack temperatures of cooled retort combustion gases, the one data point in column 4 suggests that these gases are cooled down to approximately 160°F. In general, an exit temperature of 300°F should be used for calculating plume rise unless specific data are available.

GAS VELOCITY

No data were available, but gas discharge velocity at each stack will vary from plant to plant and within each plant depending upon existing plant operations. An exit velocity of 25-50 fps should be assumed for stacks associated with primary zinc smelters.

STACK HEIGHT

Zinc smelters will utilize several stacks to discharge process effluent gases. Stack height will vary from plant to plant and within each plant. Primary operations at one plant had stacks exceeding 150 feet in height; stack heights should be assumed as 200 feet unless data are available.

TABLE VI-5.1

EXHAUST GASES FROM PRIMARY ZINC SMELTERS[2]

CAPACITY			EXHAUST GAS FLOW RATE (scfm)		
Plant No.	Capacity Tons/Year	lb./hr.	Roaster	Sintering^1 or Calcining^2	Furnace
1	252,000	57,480	99,878	--	Electrolytic
2	88,000	20,080	33,821	--	Electrolytic
3	88,000	20,910	23,463	24,520^1	--
4	59,000	14,910	16,910	6,341^2	--
5	92,000	25,490	24,308	--	Electrolytic
6	116,000	26,490	--	--	Electrolytic
7	92,000	23,240	--	158,536^1	--
8	44,000	10,500	10,041	--	169,000*
9	215,000	49,060	46,187	61,829^1	Electrothermic
10	105,000	24,990	25,154	--	--
11	53,000	12,080	130,000	100,406^1	--
12	56,000	12,740	175,447	23,463^1	--
13	47,000	10,910	--	--	40,200
14	45,000	10,750	--	--	Electrolytic

* SCFM out of stack from sinter plant and furnace including cooling water and/or dilution air.

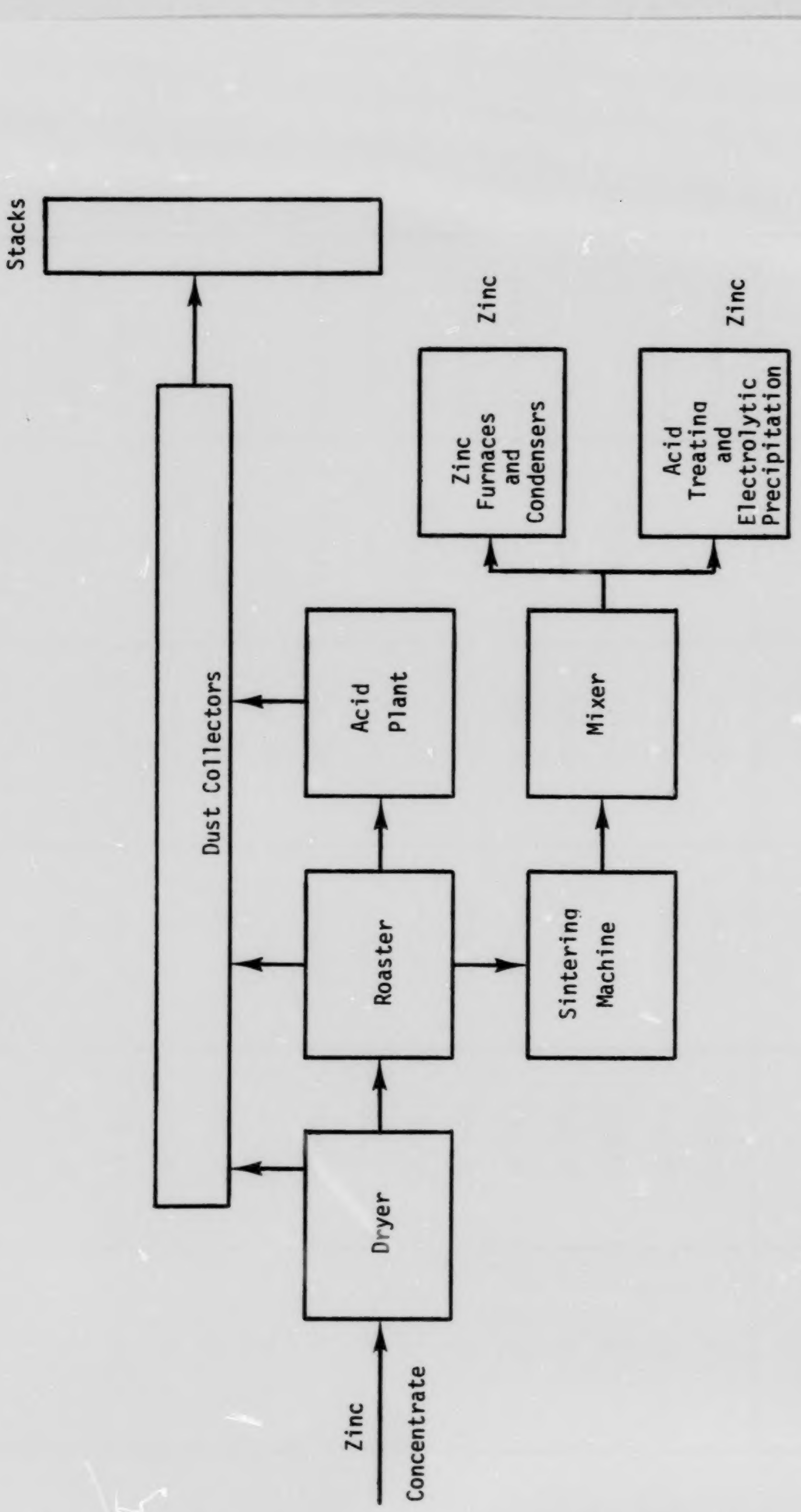
Zinc Concentrate
Dryer
Roaster
Acid Plant
Dust Collectors
Stacks
Sintering Machine
Mixer
Zinc Furnaces and Condensers
Zinc
Acid Treating and Electrolytic Precipitation
Zinc

Figure VI-5.1 Flow sheet of a primary zinc smelter

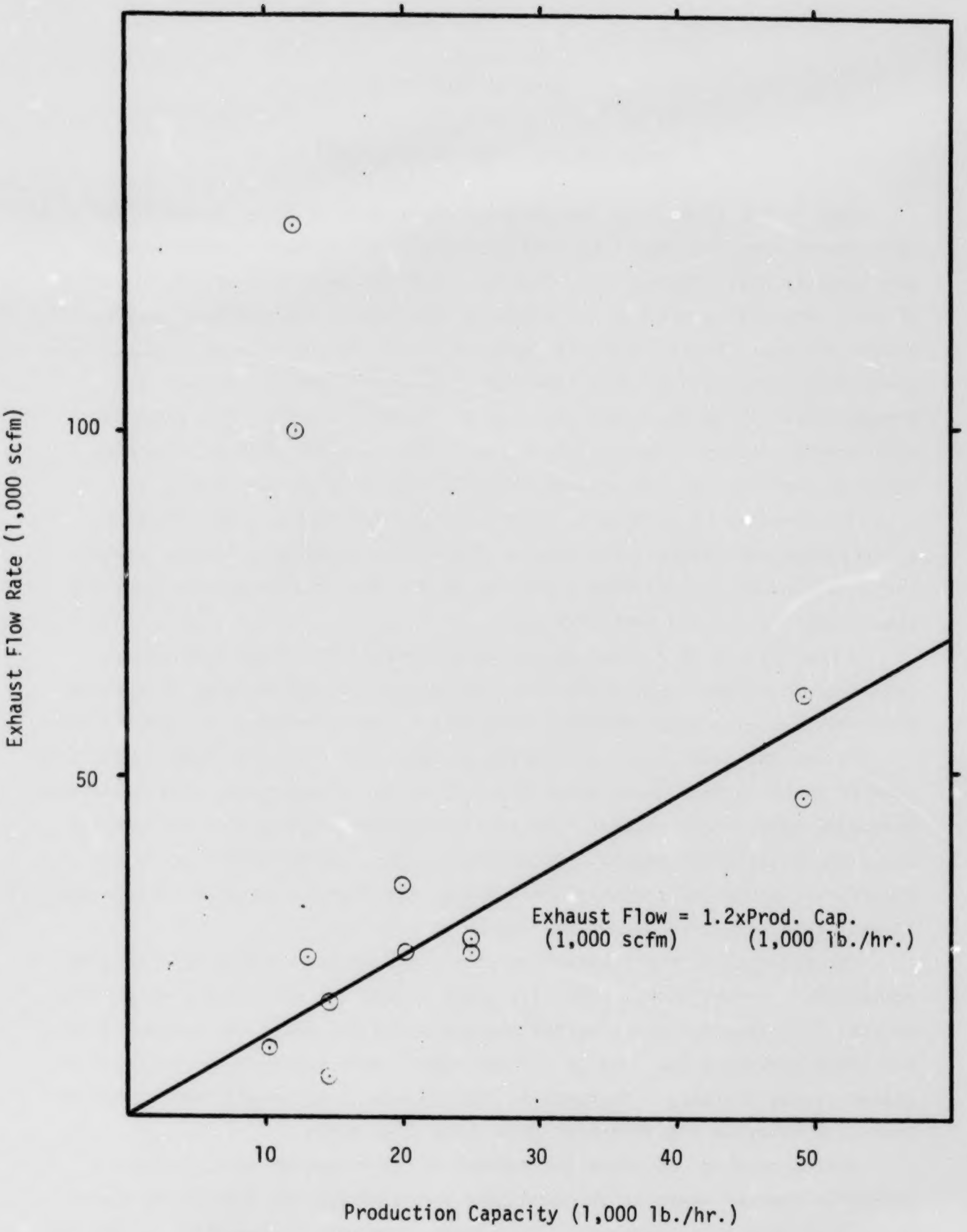

Figure VI-5.2 Exhaust flow rates from zinc roaster, sintering machine, and calciner vs. plant production capacity

CHAPTER VI-6

METALLURGICAL COKE MANUFACTURE[C]

Coke is the major fuel and reducing agent used in blast furnaces for iron manufacture and other metallurgical production operations. Technological developments have resulted in a decrease over the past 10 years in the amount of coke required to produce a ton of pig iron from 1,600 pounds to 1,250 pounds per ton. Still, there are some 60 plants in the U. S. producing about 80 million tons of coke annually. Sixteen plants are located in Pennsylvania, 12 in Ohio, and the rest in 14 other states. A typical plant will have a battery of about 100 slot type ovens. Each oven will receive about 27 tons of coal and produce about 20 tons of coke per cycle.

The manufacture of metallurgical coke is carried out primarily in by-product type coke ovens. The alternative coking technique, beehive coking, has been limited to less than 1 percent in the American integrated iron and steel industry for the last five years.

Figure VI-6.1 is a flow diagram of a typical by-product coke plant. Emissions from coke ovens arise from charging coal, discharging or pushing coke, leaking oven doors during carbonization, and quenching of finished coke.

During the 18-20 hour carbonizing period, coke ovens are heated with coke oven or blast furnace gases which are rich in carbon monoxide. Under ordinary operating conditions, exhaust from this combustion process does not contain significant air contaminants. Accordingly, these exhaust gases are not a significant source of pollution unless coal gas from the ovens leaks into the flues. This sometimes occurs in older plants.[4]

The majority of the losses from coke ovens occur during the charging operation.[9] Other losses primarily occur during the discharging or pushing of coal. Leaking may occur around the ports and the end doors during coking, but these emissions are usually a "mere wisp"[4] when compared to the gases released during charging. No specific control equipment is utilized to reduce smoke and volatile gas emissions from these coke ovens.

During pushing the open-air release of incandescent coke produces a considerable induced draft in the immediate surroundings, and fine particulates are blown high into the atmosphere. This draft, however, is comprised almost completely of ambient air, and any oven losses consist mainly of blown particulates.

With proper coking cycles and oven heating practices, however, these particulate emissions are minimal.

The pushed coke is received into an open hopper car of special design, with a sloped bottom and side gates made of grating. This car may be self-propelled or moved by locomotive to a large brick chimney that fits over the open top of the car. Sprays in the chimney deluge the hot coke with water to cool and quench it. During the quenching operation, substantial quantities of steam are generated which rise up the chimney carrying particulate matter with it. These particulates tend to fall out locally in the vicinity of the quenching tower and usually are not carried great distances as a suspended dust plume. The quenching time is about 2 minutes depending on the practice in any particular plant.

GAS FLOW RATE

Coking coal generates a considerable volume of volatile material estimated at 20 - 30% of the incoming coal. These volatilized gases amount to 7.8 - 13.4 scf/lb. of coke produced.[10] A centrifugal exhauster collects the majority of the gases from the ovens during the coking process for further processing downstream in the by-product plant. No data were found on the gaseous emission rate from coke ovens. However, if it is assumed that 0.1% of the volatilized gases (0.1% of 10 scf/lb. coke) escapes into the atmosphere, then the estimated volume of exhaust gases discharged to the atmosphere would be 0.01 cubic feet/lb. of coke produced.

GAS TEMPERATURE

The temperature of the gases escaping during the charging cycle generally approximates 550°F.[9] A similar temperature is expected during coking or pushing. Quenching tower gases are expected to be about 200°F.

GAS VELOCITY

A coke oven, processing about 27 tons of coal per day, has 4 or 5 coal-charging ports each about 10-14 inches in diameter.[4] These openings provide an area of 2.2 to 5.4 sq. ft. through which the gases escape. Resulting velocities of gases escaping through these ports at 550°F approximate 10 fps.

STACK HEIGHT

There is not a normal stack associated with the coking process, and all smoke and exhaust gases are exhausted at an elevation of about 10 - 20 feet. Quenching towers would exhaust at elevations of about 50 feet.

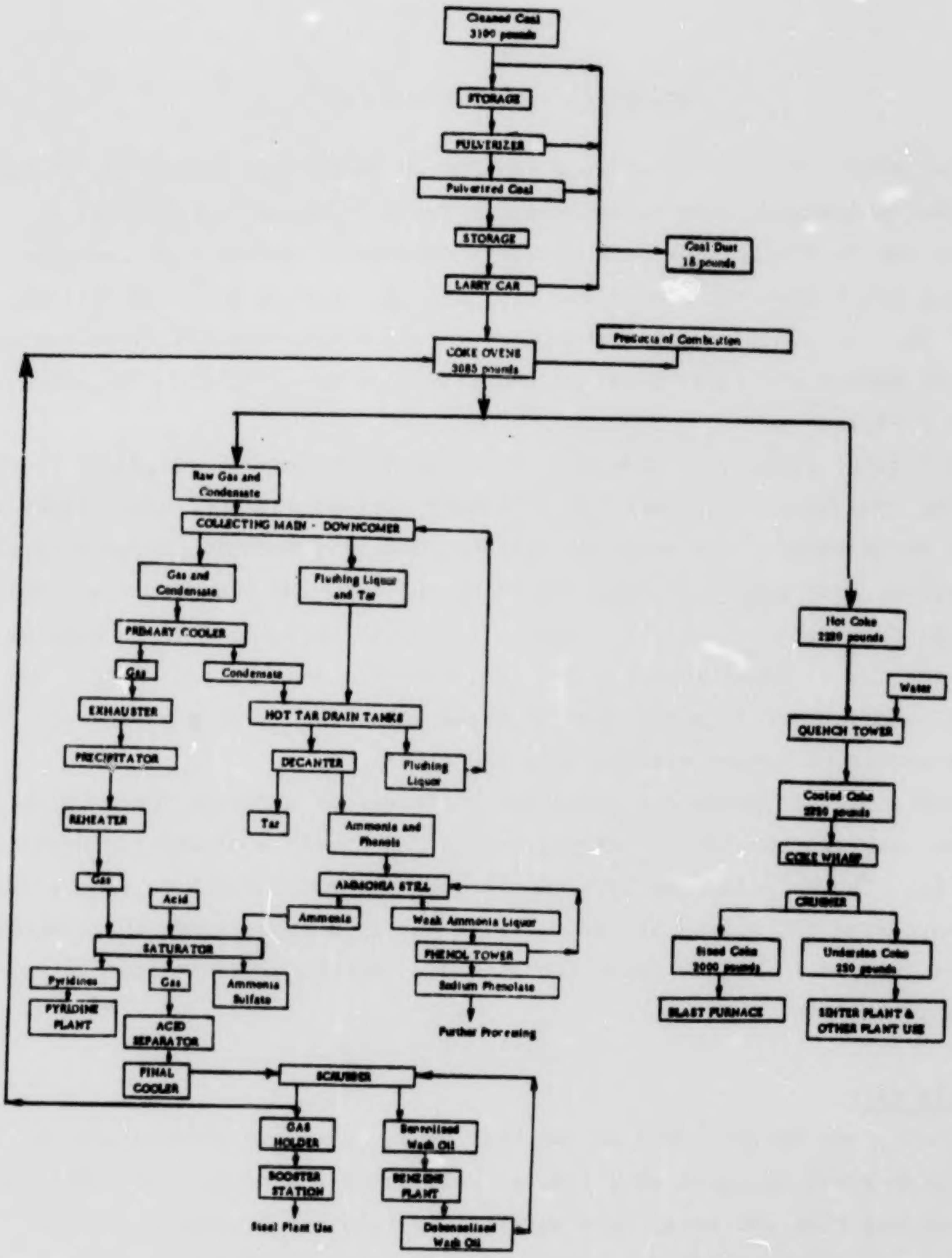
Cleaned Coal
3100 pounds
STORAGE
PULVERIZER
Pulverized Coal
STORAGE
Coal Dust
18 pounds
LARRY CAR
COKE OVENS
3085 pounds
Products of Combustion
Raw Gas and Condensate
COLLECTING MAIN - DOWNCOMER
Gas and Condensate
Flushing Liquor and Tar
PRIMARY COOLER
Gas
Condensate
EXHAUSTER
HOT TAR DRAIN TANKS
PRECIPITATOR
DECANTER
Flushing Liquor
REHEATER
Tar
Ammonia and Phenols
Gas
Acid
AMMONIA STILL
Ammonia
Weak Ammonia Liquor
SATURATOR
PHENOL TOWER
Pyridines
Gas
Ammonia Sulfate
Sodium Phenolate
PYRIDINE PLANT
ACID SEPARATOR
Further Processing
FINAL COOLER
SCRUBBER
GAS HOLDER
Benzolized Wash Oil
BOOSTER STATION
BENZENE PLANT
Steel Plant Use
Debenzolized Wash Oil
Hot Coke
2220 pounds
Water
QUENCH TOWER
Cooled Coke
2230 pounds
COKE WHARF
CRUSHER
Sized Coke
2000 pounds
Undersize Coke
250 pounds
BLAST FURNACE
SINTER PLANT & OTHER PLANT USE

Figure VI-6.1 Flow diagram of a typical by-product coke plant

CHAPTER VI-7

SECONDARY ALUMINUM SMELTER [B]

Secondary aluminum operations consist of remelting, demagging, alloying and casting aluminum from scrap aluminum parts. The melting process is carried out in crucible or reverberatory furnaces. Crucible or pot-type furnaces are indirectly heated and are used for melting small quantities, e.g. 1,000 lbs. of aluminum. Reverberatory furnaces are directly fired and are used for medium and large capacity heats or batches of 2,000 - 200,000 lbs. (Table VI-7.1).

A typical plant will have 4 or 5 furnaces and produce 100,000 - 1,000,000 lb./day. One heat is produced in a 24-hour period; however, batch times vary from 4 to 72 hours. The material charged, charging methods, furnace capacity and design, heat-input, fluxing, refining and alloying procedures all influence the time required to complete a heat. Two other operations are common to these smelters. Sweat furnaces are used to melt aluminum off of iron and other metals. Barings or turnings from aluminum metal fabricating plants are fired with a burner to remove cutting oils and grease.

Emissions are primarily magnesium and aluminum chloride fumes which react with moisture in the air to form magnesium and aluminum oxides and hydrogen chloride. The chlorine gas is blown through the metal batch to remove magnesium and gases from the molten aluminum. High energy scrubbers are the commonly used control equipment. Black smoke from the oil burning operation can be controlled with afterburners.

GAS FLOW RATE

During the melting part of the heat cycle, when the burners are on, the combustion gases are generally free of pollutants and no controls are necessary. This assumes that the scrap feed material is relatively clean. However, emissions of aluminum and magnesium chloride require control during the charging, degassing and demagging operations. During these operations, however, the burners are off and the volume of gases generated are significantly less than if combustion gases were also present. The exhaust rate then will depend entirely on the chlorine gassing rate. Stack gas flow rates from reverberatory furnaces in California during the charging, degassing and demagging operations ranged from 0.25 to 1.0 scfm per lb./hr. of metal processed.[11] In New Jersey three plants showed gas flow rates between 0.1 and 2.5 scfm per lb./hr. of metal processed.[12] It is very likely that the low flow rate was reported for demagging operations, and the high values represent straight melting operations, although such details were not specific.

GAS TEMPERATURE

The temperature of molten aluminum metal in reverberatory and crucible furnaces generally ranges from 1300 - 1350°F.[7] Gases emitted from the furnaces at these temperatures are combined with ventilation air prior to entering ventilation hoods. In order to control the fluoride and chloride emissions during the fluxing, degassing and demagging operations, wet scrubbers are generally utilized and may be followed by a baghouse or electrostatic precipitator to control solids. A typical stack temperature following such air pollution abatement equipment is 200°F.[7] Temperatures from 3 New Jersey plants ranged from 300 - 700°F. Where control equipment is not utilized, 500°F should be assumed.

GAS VELOCITY

Stack gas velocities for three California secondary aluminum smelters during charging, degassing and demagging on reverberatory furnaces ranged from 17 - 23 fps. The three New Jersey plants showed velocities between 1 and 25 fps, but the velocity of 1 fps is highly suspect. Where data are not available, assume 20 fps for calculations.

Stack Height

Based on several observations in the industry, stack heights for a typical aluminum smelting operation will range from 15 to 75 feet with an average value of approximately 40 feet. Four stacks for which data were reported ranged from 33.5 to 65 feet. Each furnace will have a separate stack.

TABLE VI-7.1

Exhaust Gases from Secondary Aluminum Smelters[12]

Input Rate 1000 lb./batch	Exhaust Flow scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Operating Time
200	400	700	1	40	17.5 hr./batch 1 bat./day
1.2	6000	-	25	33.5	8 hr./day 5 days/wk.
200	400	700	1	40	15.5 hr./batch 1 bat./day
3		300	25	65	6 hr./batch 1.5 bat./day

CHAPTER VI-8

SECONDARY BRASS AND BRONZE SMELTER ^{C}

Currently, there are approximately 60 brass and bronze ingot producers in the U. S. averaging slightly more than 300,000 tons annually.[13] In addition to the ingot manufacturers, the industry is also comprised of foundries, dealers, collectors and about a dozen primary smelters using scrap and mineral concentrates.

The principal sources of atmospheric emissions in brass and bronze smelting are the furnaces used to melt, smelt, refine and alloy the processed scrap material. Reverberatory, rotary, or crucible furnaces are used depending on the alloy manufactured or the melt size. Stationary reverberatory furnaces refine heats of from 50 - 100 tons in 24 - 48 hour periods. When such large batches are not required, the cylindrical rotary furnace is most often used. These furnaces range in size from only a few tons up to 30 to 40 tons. Both these furnace types are heated directly, i.e. the flame and gases come in direct contact with the melt. Crucible furnaces, which are heated indirectly, produce special-purpose alloys.

Operating times of brass and bronze smelters vary, but limited experience with such smelting operations indicates that the plants operate 2 - 3 shifts per day, 5 - 6 days per week.[14]

Emissions are primarily metal fumes (oxides of copper, zinc, lead, etc.), and the common type of control equipment is baghouses.

GAS FLOW RATE

Limited data indicate that dust concentrations from these furnaces range from 0.05 to 4.1 grains per scf, with average emission factors of 60 - 80 lbs. of particulate per ton of metal produced.[13] From these values, gas volumetric flow rates can be calculated to range from 1 to 82 scfm per lb./hr. of metal produced. A more realistic range is 2 - 14 scfm per lb./hr. of metal produced, with an average of 6.5. Two New Jersey plants reported gas flow rates of 5000 scfm for a 1000 lb./hr. continuous melt and 7300 scfm for a 200 lb./hr. batch operation.[12] These convert to 5 and 37 scfm per lb./hr. of metal produced. Where no data are available, assume 10 scfm per lb./hr. of metal produced.

GAS TEMPERATURE

Smelting furnaces are generally operated at temperatures between 2000 and 2200°F.[13] Gases discharge at these temperatures but are cooled prior to passing through appropriate air pollution control systems. Large quantities of ventilation air enter the system at the hood-furnace interface and serve also to cool the furnace gases. Water sprays and radiation cooling are commonly utilized to further reduce the flue gas temperature. Indirect cooling utilizing cooling towers is also practiced. Baghouses are the most common type of control equipment. Typical operating temperature for these baghouses, and therefore stack temperatures, range from 150 - 275°F. If glass fibers are utilized as the filter media, temperatures of up to 500°F can be tolerated. Data for two plants showed 70°F and 250°F as exit temperatures. Where information is lacking, 200°F should be assumed. Without control equipment 500°F may be assumed.

GAS VELOCITY

Stack gas velocities for 11 brass smelters ranged from 32 - 70 fps with an average of 53 fps.[11,12] Where no data exists, 50 fps should be assumed.

STACK HEIGHT

Stack heights for brass and bronze foundries normally can be found in the range of 20 - 50 feet. Two plants had stack heights of 20 and 26 feet. An average value of 30 feet may be assumed.

CHAPTER VI-9

GRAY IRON FOUNDRY [c]

Gray iron foundries produce a heavy, brittle metal commonly called cast iron, but named after its characteristic gray-white color. There are over 6,000 foundries in the United States which use over 3,300 cupolas. Cupolas are used to melt over 90% of the metal poured for gray iron casting. They range in capacity from 1 to 50 tons of melted metal per hour with over 60% ranging from 3 to 11 tons per hour. However, electric furnaces are gaining in popularity partially because of the lower emission characteristics associated with this furnace. Reverberatory and crucible furnaces are occasionally utilized, but their combined usage is less than 2% of all foundries and they generate relatively low quantities of emissions.[15]

Table VI-9.1 shows operating characteristics for 6 plants with cupolas ranging from 4 to 20 tons per hour.[15] Approximately 95% of all cupolas fall within this range. As seen, melt times vary from 3 - 16 hours per day and foundries operate from 175 to 250 days per year.

A flow diagram of a typical pattern shop and gray iron foundry is shown in Figure VI-9.1. Principal emissions from iron foundries are iron oxide dust and fume and carbon monoxide. Major controls are precipitators and venturi scrubbers, although only a small precent of the total number of foundries are controlled.

GAS FLOW RATE

Data from two New Jersey cupolas showed exhaust rates of 7,000 scfm from production of 7,000 lb./hr. of iron and 45,540 cfm from producing 34,000 lb./hr. of iron.[12] Both exhaust volumes were at 165°F. so correcting to 70°F gives 0.8 to 1.1 scfm per lb./hr. of iron produced. Another cupola in Ohio melted 70,000 lb./hr. with a steady blast of 14,500 cfm. Wet exhaust gases after a scrubber totalled 70,000 cfm at 160°F with 31% moisture.

Because of the many types of flue gas conditioning systems employed, stack gas flow rates may be expected to vary somewhat. However, since about 1 lb. of air is blown through the cupola tuyeres per lb. of iron produced, and from 200 - 500% infiltration air enters through the charging ports, the resultant volumetric flow rate will generally be 0.62 - 1.25 scfm per lb./hr. of iron produced.[16] Figure VI-9.2 may be of further assistance in determining exhaust gas flow rates from gray iron foundrys.

GAS TEMPERATURE

Gases from cupola furnaces range from 1500 - 2000°F.[15] These gases are generally vented directly from a cupola sealed at the top to a control system or alternatively vented out the top of the cupola directly if no control system is utilized. The control system generally consists of an afterburner, flue gas conditioning and a baghouse or electrostatic precipitator. Cooling may be accomplished by dilution air, water sprays, radiation-convection columns or a combination of these. Of the three, water sprays are the most commonly employed.[7] Stack gas temperatures following control systems generally range from 200 - 500°F.[7] The three foundries for which data were available had exit temperatures of 160, 165, and 166°F. Therefore, assume 200°F whenever specific data is lacking.

GAS VELOCITY

Velocity data for 3 gray iron cupolas located in Los Angeles County ranged from 32 - 42 fps. Two in New Jersey had velocities of 39 and 53 fps. The one in Ohio had a stack velocity of 61 fps. When data are unavailable, 40 fps may be assumed.

STACK HEIGHT

Stack heights normally increase with foundry size but generally fall in the 50 - 100 foot range with an average height of approximately 75 ft. Large foundries have stacks on the order of 200 feet. For calculating assume 75 feet.

TABLE VI-9.1

Typical Gray Iron Foundry Operating Characteristics [12]

Melt rate/cupola, tons/hr.	Melt time		Number of cupolas
	hr./day	days/year	
4	3	175	1
6	5	200	1
8	7	225	1
12	9	240	2
16	12	250	2
20	16	250	2

TABLE VI-9.2

Exhaust Gases From Gray Iron Foundry Installations[7]

Cupola Capacity lb./hr.	Exhaust Flow scfm	Exhaust Temp. °F
8,380	5,520	1,400
14,000	20,300	430
16,800	8,430	482
24,650	17,700	210
8,200	8,300	1,085
36,900	21,000	222
39,100	30,500	213

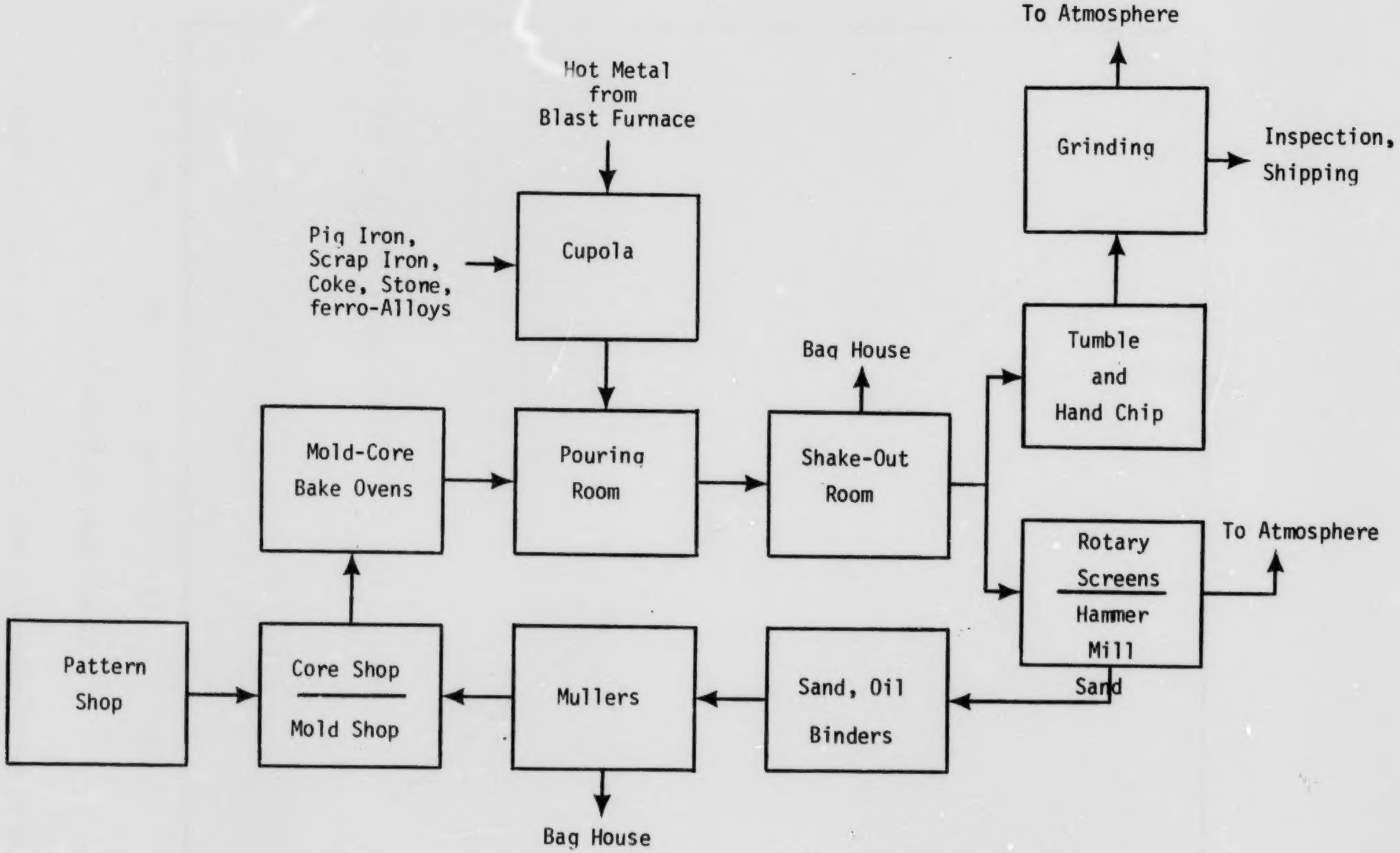
To Atmosphere
Hot Metal from Blast Furnace
Grinding
Inspection, Shipping
Pig Iron, Scrap Iron, Coke, Stone, ferro-Alloys
Cupola
Bag House
Tumble and Hand Chip
Mold-Core Bake Ovens
Pouring Room
Shake-Out Room
To Atmosphere
Rotary Screens
Hammer Mill
Sand
Pattern Shop
Core Shop
Mold Shop
Mullers
Sand, Oil Binders
Bag House

Figure VI-9.1 Flow diagram of pattern shop and gray iron foundry

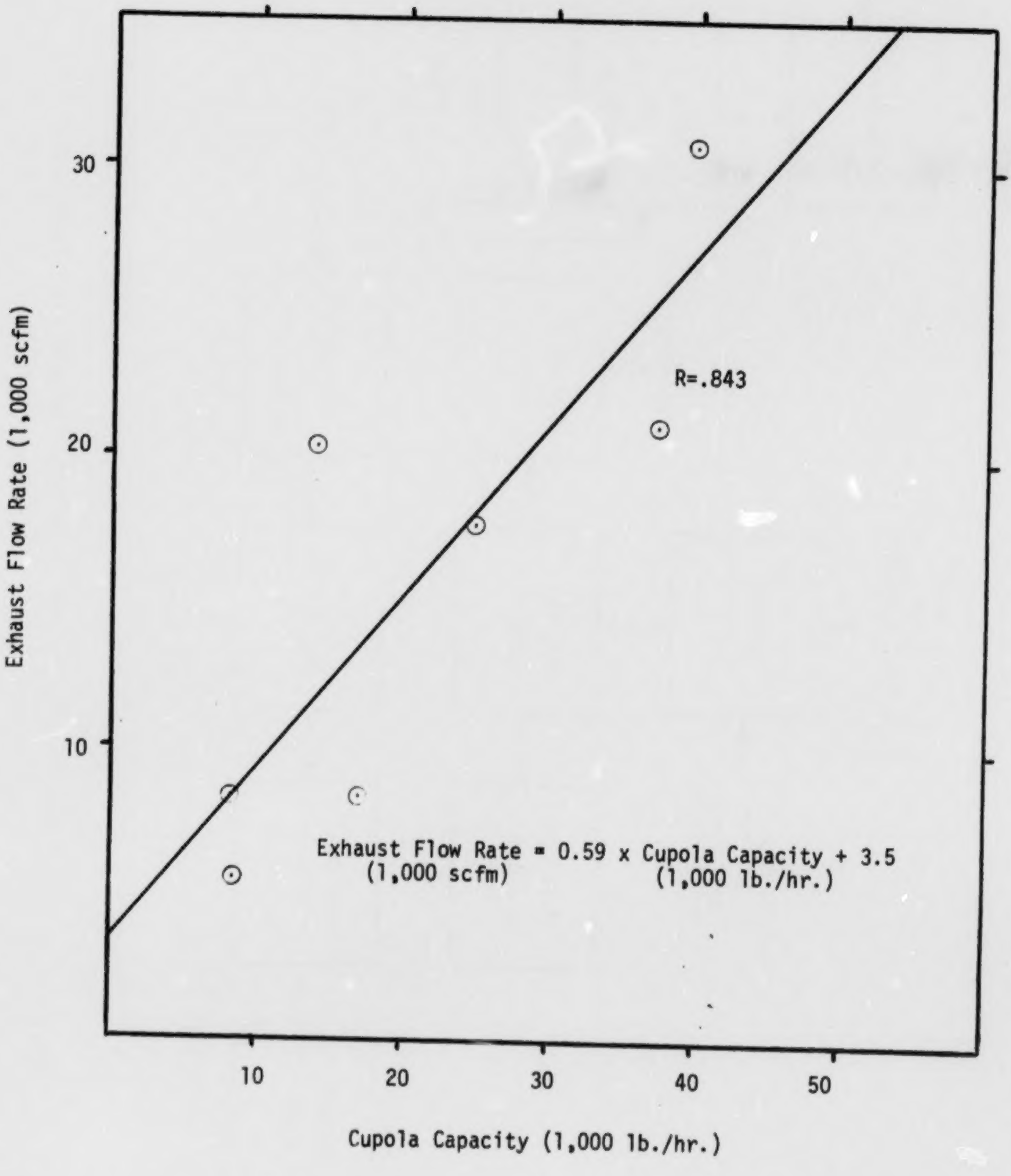

Figure VI-9.2 Exhaust Flow rates for various size gray iron foundry installations.

CHAPTER VI-10

SECONDARY LEAD SMELTER[C]

There are about 50 secondary lead smelters in the United States. Some of the plants also manufacture lead batteries and utilize scrap batteries as their input materials, but the actual degree to which the two operations are combined is not known. A typical plant will produce on the order of 50,000 lb./day of lead ingot. Although no information was found in the literature regarding operating times of secondary lead smelters, it is assumed to be similar to other secondary smelters, i.e. operating 2-3 shifts per day and 5 to 6 days per week, depending on product demand.

Lead smelting is conducted in blast furnaces, pot furnaces or reverberatory furnaces. The nature of each furnace and their resulting emissions vary enough so that a discussion of each furnace is presented later.

Emissions are primarily lead oxide fumes, although other metals, silica, and sulfur oxides will be present. Principal control devices are baghouses or precipitators. Gases are cooled by dilution air, radiation, or water prior to entering the control equipment.

GAS FLOW RATE

The gases leaving reverberatory furnaces, which operate under positive pressure to sustain the required lead bath temperature, combine with ventilating air and are ducted through external hoods to collectors. As mentioned above, such collection devices generally consist of baghouses with the typical techniques for gas cooling employed. Data for one reverberatory furnace[7], utilizing indirect heat exchange cooling techniques in addition to ventilation air, showed a stack gas flow rate of 4.2 scfm per lb./hr. of metal produced. Another investigator indicated that a dross reverberatory furnace with no collection devices generated approximately 1.1 scfm per lb./hr. of lead processed.[11] Other tests showed exhaust gases to total 9,350 scfm from a reverberatory furnace.

Lead blast furnaces or cupolas are very similar to the cupolas utilized in the gray iron foundry industry.

Blast furnace gas temperatures exit at temperatures from 1200 - 1350°F.[7] Afterburners may be necessary to control the combustible emissions in the effluent since carbon monoxide concentrations range from 1 to 10 percent. The gases are generally vented directly to a control system after being cooled or receiving some type of gas conditioning. Cooling may be accomplished by dilution air, water sprays, radiation-convection columns or a combination of these.

Because lead blast furnaces or cupola operations are similar to the cupolas used in the gray iron foundry industry, volumetric flow rates presented in Chapter VI-9 apply here. Data for one lead blast furnace installation show a stack volumetric flow rate of 4.95 scfm per lb./hr. of metal processed. This furnace utilized dilution air for cooling and, therefore, falls within the range (2.5 - 5.0 scfm per lb./hr. of metal processed) estimated in the section on gray iron foundries for dilution cooling.

Since pot furnaces are indirectly fired, their pollution potential is much less significant than either the blast or reverberatory furnaces. These furnaces vary in size from 1-50 tons and are utilized primarily for alloying and refining. No data were found on gas flow rates. Based on experience in the steel industry, lead pots would be expected to have flow rates on the order on one-tenth that of the reverberatory furnace or 0.1-0.4 scfm per lb./hr. of metal produced.

GAS TEMPERATURE

Gases exiting from the melting furnaces are 1200-1400°F. However, dilution and cooling prior to clean-up lowers temperatures to about 300°F. Temperatures on the stack following a baghouse serving both a reverberatory and blast furnace were 200°F. Since most lead smelters would be controlled, 200°F should be assumed for exit gas temperature.

GAS VELOCITY

Data from one set of stack tests showed the combined exhaust exit velocities to be 32 fps prior to the baghouse and 50 fps afterwards. Stack diameters were 29 inches on two cooling inlet pipes and 36 inches on one outlet stack.

STACK HEIGHT

Observations at one plant indicated a steel 36" diameter stack with a height of about 100 feet.

CHAPTER VI-11

MAGNESIUM SMELTING [B]

Magnesium smelting is done in small steel pots having a capacity of between 500 and 5,000 lb./batch. Each smelt takes about 8 hours: 2 hours charging, 2 hours melting (at about 1200°F), 4 hours pouring and 2 hours for clean out. Plants usually operate 2 or 3 shifts per day depending on the market demand. Magnesium scrap is usually made up of oily Volkswagen engine blocks, magnesium shavings/turnings, bomber wheels etc. The major pollutants are particulates in two forms. During charging, the oily material burns and black soot (of about Renglemann 5) is visible for a few seconds after each "hand full" of scrap is added. The other form of particulates is submicron in size emanating during the entire process and are metal fumes. Fluxes contain about 98% Cl^- (like $MgCl_2$, $BaCl_2$ and KCl) and about 2% F^- (like CaF_2). As a result HCl is given off in high concentrations, 200 ppm over the duration of the cycle. Natural gas is usually the heat fuel for the pots. Very few plants have any control equipment. Those that do control particulates would use a high energy scrubber or a baghouse.

Plant capacity depends on the number of pots. Some of the pots may have heat shields, conical in shape, which also serve as an "inner stack". From the inner stack, pollutants are hooded to several roof top ventilation fans.

GAS FLOW RATE

The gas flow rate for one plant having several lines ranged from 800 to 1100 scfm for the entire 8 hour cycle at the inner stacks.[17] The exit flow at roof top depends on the power of the fans. One plant having 6 roof top fans had a total exit flow of 180,000 scfm for a capacity of 8,000 lb./hr.[17]

GAS TEMPERATURE

The gas temperature about 15 feet above the molten metal will range from 160 to 320°F unit a mean of 220°F for the 8 hour cycle. Hoods and dilution air will make the temperature at roof top 90°F.

GAS VELOCITY

The velocities for one plant having several pots ranged from 10 to 14 fps at the pot inner stack. Roof ventilation, however, is commonly used, and exit velocity will depend on fan size. The exit velocity at the roof is about 20 to 25 fps.

STACK HEIGHT

Common stack heights for smelting operations are about 65 feet. Because ventilation fans are mounted in the roof apex, there is not the traditional round or square stack protruding several feet above the roof top.

CHAPTER VI-12

STEEL FOUNDRIES [C]

Steel foundries differ from the basic iron and steel plants since their primary raw material is scrap steel (instead of pig iron). Steel foundries produce cast steel, as a finished product, usually for heavy industrial end uses like the frame of a bulldozer, locomotive wheels, etc. There are about 400 steel foundries operating in the U. S. Typical plant sizes depend on the number of furnaces but range from 25 to 240 tons per day. There are five types of furnaces: direct electric, electric induction, open hearth, crucible and pneumatic converter.

Particulate emissions from the foundry include iron oxide, sand fines (from the casts), graphite, and metalic dust. Gaseous emissions include NO_x, SO_x and hydrocarbons. Most plants will use air pollution abatement devices except plants having electric induction furnaces. At minimum, all plants will have some ventilation system to remove heat from the work area. Common types of control equipment include electrostatic precipitators, venturi scrubbers and baghouses. The operating times of steel foundries is continuous 24 hours a day and 7 days a week for large plants and intermittent for small plants (average 8 hr./day).

GAS FLOW RATE

Exhaust gas flow rates for three steel foundries ranged between 1 and 5 scfm per lb./hr. for plants using control equipment as well as those which used only a roof ventilation system. Exhaust flow averaged 3.3 scfm per lb./hr. capacity. See Table VI-12.1.[12,17]

GAS TEMPERATURE

The exhaust gas temperature is about 150°F because of the dilution air needed to cool the work area. (Furnace gas temperatures range from 2,000 to 3,000°F.) The range for the data was 80 to 675°F for exit temperatures.

GAS VELOCITY

Typical exit velocities will be 50 fps. From the data collected the exit velocity ranged from 50 to 60 fps for both plants having control equipment and plants having only ventilation fans.

STACK HEIGHT

The stack heights for 3 foundries ranged from 55 to 85 feet. Typical stack heights fall in this range, and 75 feet should be used for calculation purposes.

TABLE VI-12.1

Exhaust Gases from Steel Foundries[12]

Input Rate	Exhaust Flow scfm	Exhaust Temp. ^oF	Stack Velocity fps	Stack Height ft.	Operating Time
90,000 lb./bat.	110,000	80	56	85	3½ hr./bat.,6/wk.
70,000 lb./hr.	60,000	150	50	75	cont.
4,635 lb./hr. 9,270 lb./bat.	3,550 24,500	675	59	55	2 hr./bat.,2 bat./wk.

CHAPTER VI-13

SECONDARY ZINC SMELTER [D]

In 1967, 73,000 tons of redistilled secondary zinc slab were produced in 13 U. S. plants.

Secondary zinc is melted in a variety of furnaces for use in alloying, casting and galvanizing. These furnaces include crucible, pot, kettle, reverberatory and electric induction units. The melting operation is essentially the same for all these units. The zinc feed may be in the form of ingots, rejected castings, flashing or scrap. Pouring temperature for the molten zinc is generally maintained between 800 and 1100°F. Fluxes are added prior to pouring and cause a dross to form at the top of the melt. Following skimming of the dross, the melt is ready for pouring into molds or ladles.

Zinc vaporization is used to reclaim zinc from alloys, refine by distillation, manufacture zinc oxide, or manufacture powdered zinc. Such operations are carried out in distillation or muffle furnaces which are heated indirectly to keep the distilled zinc fumes separated from the fuel combustion gases. Such furnaces are operated at temperatures between 1800 and 2300°F for 10 to 12 hours.[11] Vaporized zinc is condensed in large water chilled condensers.

Emissions are principally zinc oxide fumes. Control equipment is generally baghouses or precipitators.

GAS FLOW RATES

Other than the products of fuel combustion, gaseous emissions are generally considered negligible during zinc melting operations. At temperatures below the pouring temperature of 1100°F, the vapor pressure of zinc is low enough so that any zinc fumes formed cannot be seen. There are some instances when fumes are generated as, for example, when a fuming flux (NH_4Cl) is used or when significant organic impurities are present. In general, however, secondary zinc melting fumes are not a significant source of gaseous emissions.

Gas flow rates from zinc distillation furnaces to the collection systems and stack range from 20 - 30 scfm per lb./hr. of zinc produced.[8] This volume includes the large quantities of dilution air that mix with the retort gases leaving the condenser. One plant reported 13,600 cfm at 90°F from producing 10,000 lb./hr. of zinc. Hoods used with various furnaces show flow rates from 2,000 - 9,000 cfm.[18] Data on two smelters showed total exhaust flows going to a baghouse and cyclone of 16,800 and 30,240 cfm. Temperature was not stated but could be assumed at 150°F.

GAS TEMPERATURE

Since pouring temperatures from melting furnaces are generally between 800 - 1100°F, it can be assumed that the temperature of any fumes generated will fall within this range.

Gases from the condenser are generally mixed with large quantities of dilution air prior to entering a collection system. The temperature of these gases leaving the control system is generally about 150°F.[11]

GAS VELOCITY

As in the case with most stacks, the exit velocity design criteria would fall in the range of 25 - 50 fps for both smelting and vaporization processes. One plant reported 33 fps.

STACK HEIGHT

One plant had stacks 45 feet high. As with other secondary smelters, stack heights are expected to fall between 20 and 50 feet. For calculation purposes, an average height of 40 feet may be assumed for both smelting and vaporization processes.

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CHAPTER VII-1

ASHPHALT ROOFING PLANT [A]

Asphalt is a residue produced as a by-product in regular petroleum refining processes. Oxidized asphalts (air blown asphalts) are commonly used in the manufacture of roofing papers and shingles and for grouting. The air blowing process used in the manufacture of asphalt roofing consists of blowing air under controlled conditions into the asphalt residue for perdetermined periods of time. The air blowing is not only a physical process but is also a chemical process for conversion of hydrocarbons. The asphalt roofing market comprises about 1/5 of the total asphalt market with 1968 sales of 5 million short tons. Asphalt roofing plants are located in every state with California leading the nation in production.[1]

Typical operational times for this continuous process are 5-6 days a week and 2 shifts per day. The points of air contaminent emission are the asphalt presaturater sprays, the saturator tank and the wet looper (Figure VII-1.1). Pollutants are organic asphalt mists and particulates. Spray scrubbers and two stage electrostatic precipators are the recommended control equipment for the wet looper and the saturator tank.[2] Since virtually no material is liberated from the sum of process weights, input-output quantities will be equal.

GAS FLOW RATE

Air volumes handled by the exhaust system vary with hood design and saturation size but range between 10,000 and 20,000 scfm where control equipment is used. Of the three operations where data were collected few control devices were used, and the exit flow rates ranged from 100 to 20,000 scfm (Table VII-1.1)[3].

For modeling purposes a flow rate of 15,000 scfm should be used on plants with abatement equipment and 1000 scfm on plants which have no control equipment.

GAS TEMPERATURE

Gas temperatures ranged from 82 to 185°F for the asphalt roofing plants with control equipment and 180 - 270°F for those plants without control. An average temperature of 110°F and 230°F should be used for plants with control equipment and without control equipment, respectively.

GAS VELOCITY

Where no control equipment is used, molding process emissions were vented through 20 - 28 inch stacks to the atmosphere with no auxillary vent fan. From the data collected, exit velocity was 4 fps. For three plants with control equipment, velocities ranged from 36 to 68 fps with a mean of about 40 fps.

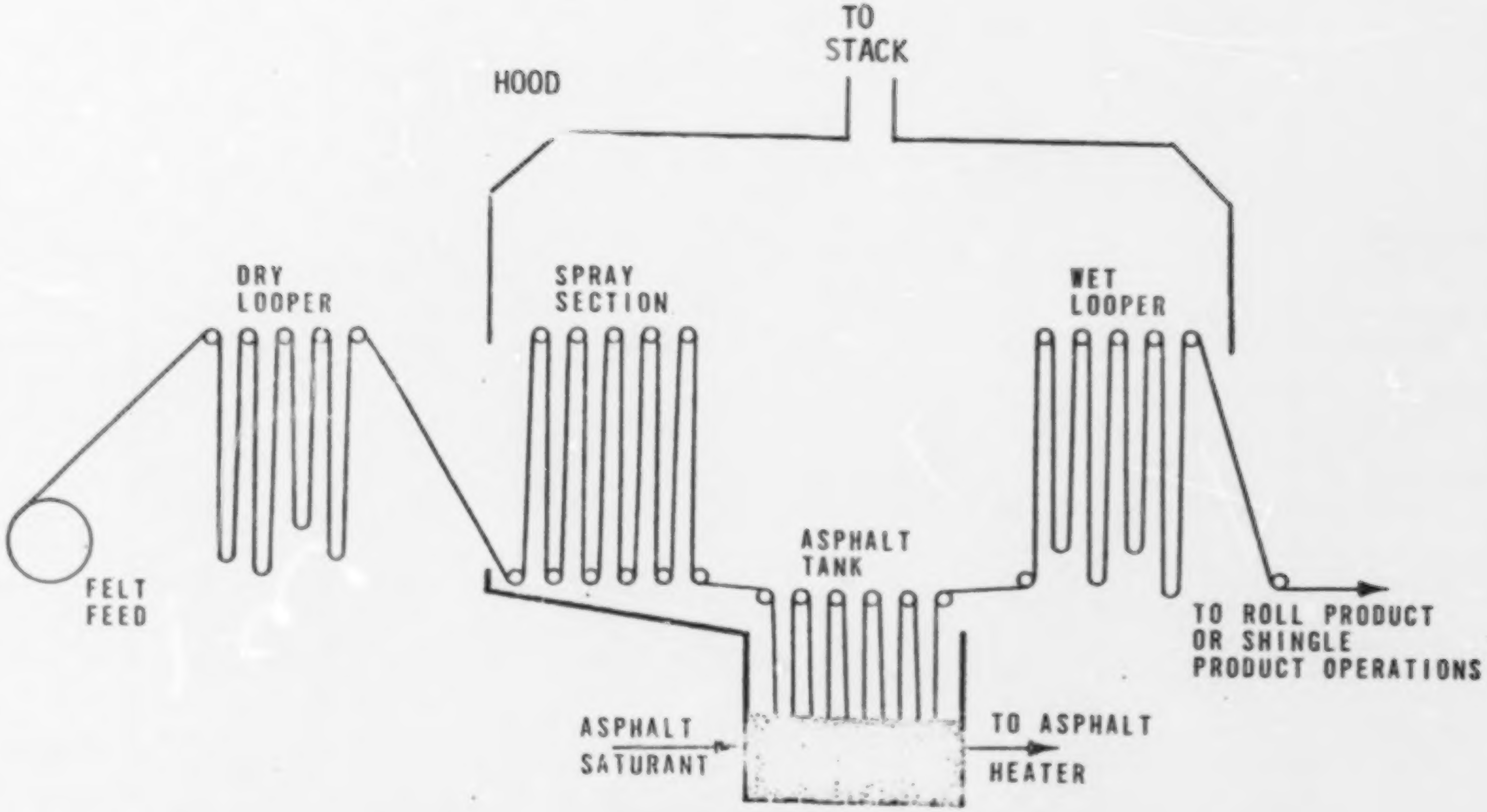
STACK HEIGHT

Stack height depended mainly on the building since the stacks are about 10 feet above the roof. For three plants without controls heights ranged from 45 to 90 feet. A stack height of 60 feet should be assumed when no data are available.

TABLE VII-1.1

Exhaust Gases from Asphalt Roofing Manufacturing[3]

Product Operation	Input Rate tons/hr.	Exhaust Flow scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameter ft.	Operating Time	Control Equipment
Roofing Felt	1.5	1050	180-270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
	4.5	1050	270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
Asphalt	2.2	1050	108-270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
	12	1050	270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
Tar	2.4	1050	180-270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
	9	1050	270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
Miscellaneous	12	100	200		90	1.67	5-6 days/wk. 2 shifts/da	Drop out tanks
		20,000	82	68.3		2.5		
		10,300	185	36.2		2.5		Scrubber-precipitator
		12,196	82	44		2.5		Bag filter & Cyclone
	7.25	12,000		40	33			Water scrubber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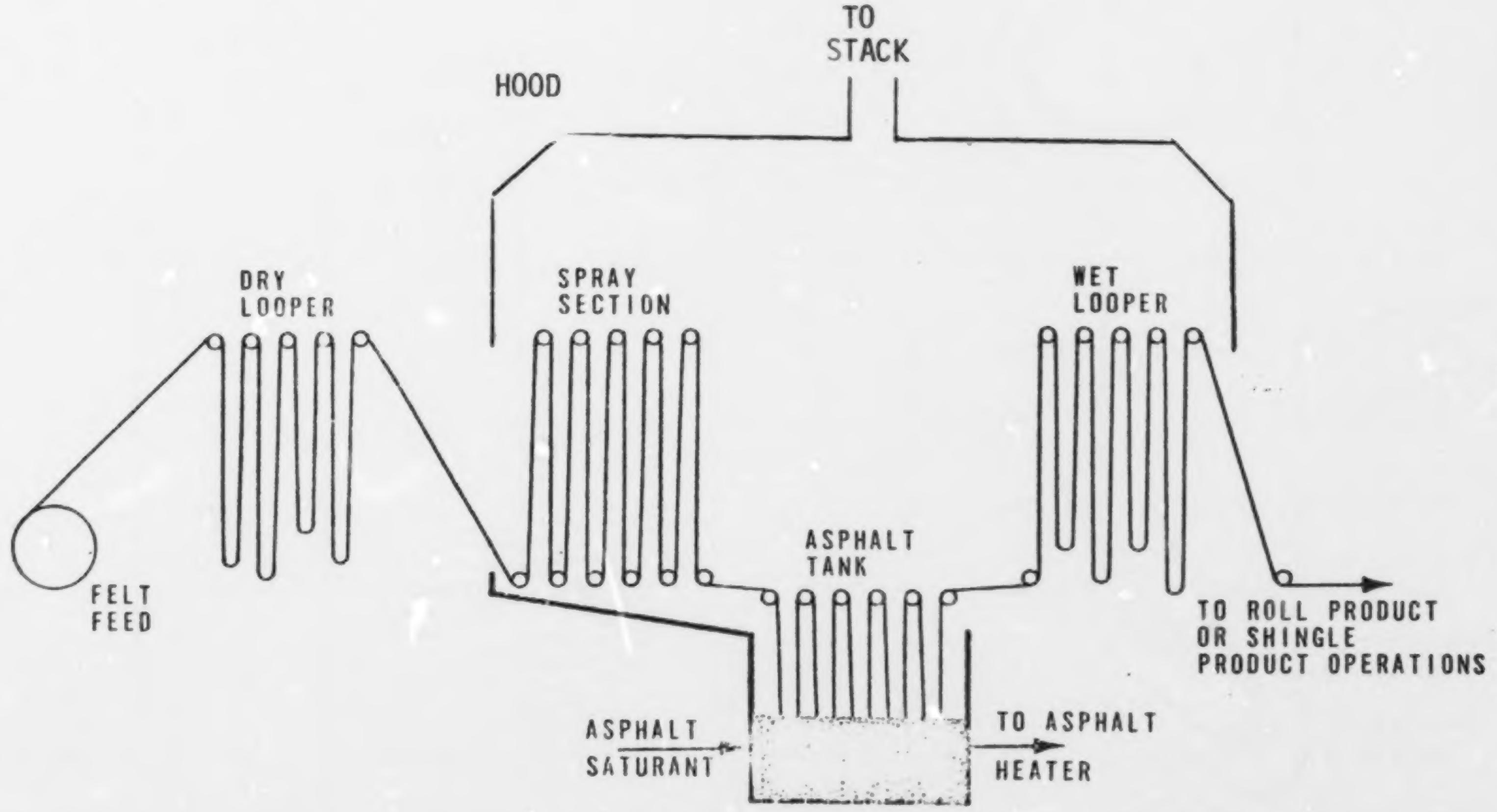
ASPHALT
TANK
TO ROLL PRODUCT
OR SHINGLE
PRODUCT OPERATIONS
ASPHALT
SATURANT
TO ASPHALT
HEATER

Figure VII-1.1 Schematic drawing of an asphalt roofing felt saturator

TABLE VII-1.1

Exhaust Gases from Asphalt Roofing Manufacturing[3]

Product Operation	Input Rate tons/hr.	Exhaust Flow scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameter ft.	Operating Time	Control Equipment
Roofing Felt	1.5	1050	180-270	4.4	45	2.34	5-6 days/wk. 2 shifts/da.	
	4.5	1050	270	4.4	45	2.34	5-6 days/wk. 2 shifts/da.	
Asphalt	2.2	1050	108-270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
	12	1050	270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
Tar	2.4	1050	180-270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
	9	1050	270	4.4	45	2.34	5-6 days/wk. 2 shifts/da	
Miscellaneous	12	100	200		90	1.67	5-6 days/wk. 2 shifts/da	Drop out tanks
		20,000	82	68.3		2.5		Scrubber-precipitator
		10,300	185	36.2		2.5		Bag filter & Cyclone
		12,196	82	44		2.5		Water scrubber
	7.25	12,000		40	33			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OR SHINGLE
PRODUCT OPERATIONS
ASPHALT
SATURANT
TO ASPHALT
HEATER

Figure VII-1.1 Schematic drawing of an asphalt roofing felt saturator

CHAPTER VII-2

ASPHALT PLANT [B]

The 1968 production of asphaltic concrete totalled 14 million tons; it was used for construction of state, county, interstate and municipal roadways, parking lots, driveways, airports and playgrounds. Typical plant sizes are on the order of 50 to 200 tons per hour. There are over 10,000 plants in the U.S. some of which are mobile to allow relocation as construction sites change.

Manufacture of asphaltic concrete is simply a blending, drying and mixing operation (Figure VII-2.1). For practical purposes, process feed rates are matched one for one with the process output since moisture in the aggregate is replaced, on a weight basis, by asphalt.

Asphalt plants run 8 hours per day, 5 or 6 days per week, from about 7:00 a.m. to 3:00 p.m. The principal emissions are dust particles eminating from the dryer kiln. Production of the fine surface mixes gives rise to the greatest dust emissions. Control equipment always includes mechanical collectors for separating products from the air stream. Scrubbers are very common, and occasionally baghouses are used to minimize dust loading.[2,4]

GAS FLOW RATE

The dryer kiln is either gas or oil fired. Suitable drying is attained when the flow velocity through the kiln is between 200 and 400 fpm. Since the gas effluent volume is determined by the type and size of drying kilns and the collection systems used, some variation was found in the literature (Figure VII-2.2). For most plants in the 100 - 200 ton/hour capacity, exhaust flow rate was between 15 and 25,000 scfm (Table VII-2.1).[2]

GAS TEMPERATURE

The temperature of exhaust gases for 4 plants was from 180 to 430°F with a mean of 225°F without control equipment. Use of a scrubber will reduce exit gas temperatures to about 100°F.

GAS VELOCITY

No data were obtained, but stack diameters are typically 3 to 10 feet. Therefore, an average of 10 fps should be used unless specific data are available.

STACK HEIGHT

Most asphalt plants have stacks over the drier exhaust, and the entire plant is elevated so that trucks can load by gravity from the mixing or storage bins. Therefore, the stack heights will be 20 - 30 feet above ground.

TABLE VII-2.1

Exhaust Gases from Asphaltic Concrete Batch Plants[2]

Production Rate tons/hr.	Exhaust Flow 1,000 scfm
183.9	23.1
96.9	19.8
174.0	26.2
209.1	25.7
142.9	18.2
158.0	18.0
113.0	16.1
92.3	19.5
118.4	7.7
137.8	18.7
184.2	17.0
144.6	23.7
191.3	28.3
114.6	24.3
124.4	15.9
42.0	17.2
182.0	22.0
138.9	24.6
131.4	18.0
131.7	18.2
174.3	20.0
114.5	19.6
198.0	21.0
152.0	22.2
116.5	17.1

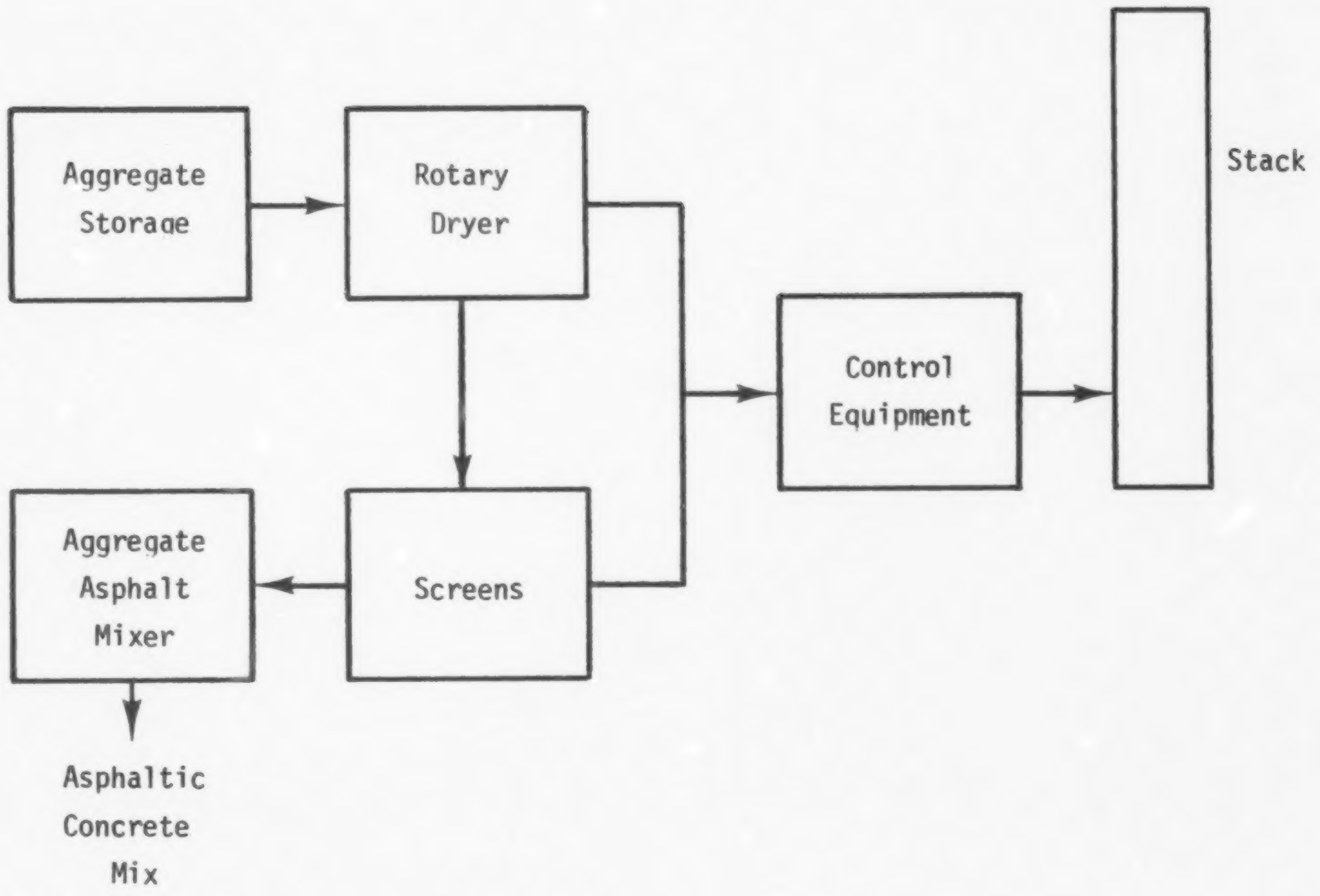

Aggregate Storage
Rotary Dryer
Stack
Control Equipment
Aggregate Asphalt Mixer
Screens
Asphaltic Concrete Mix

Figure VII-2.1 Flow diagram of a typical hot-mix asphalt paving batch plant

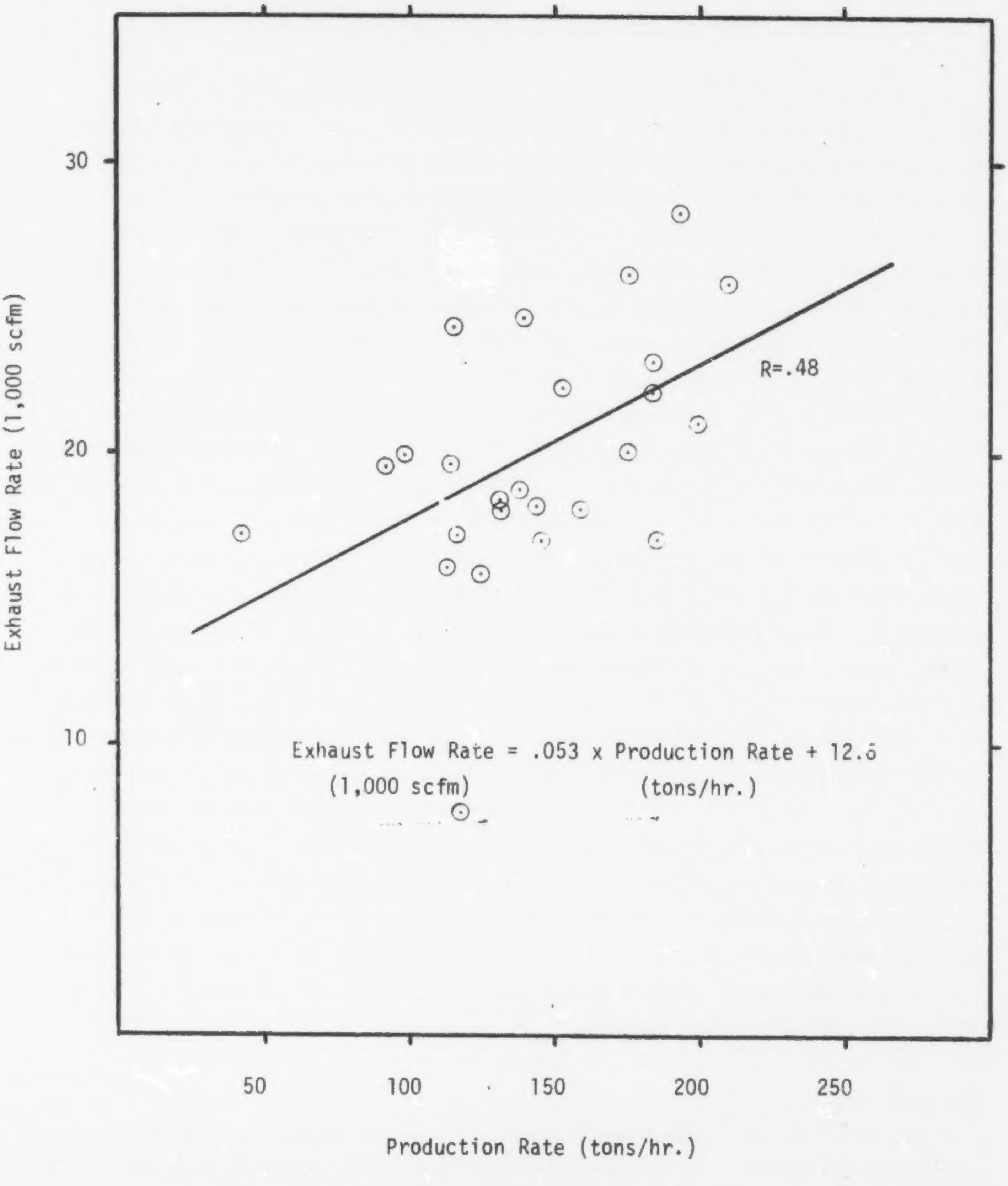


Figure VII-2.2 Exhaust flow and production for asphaltic concrete batch plants

CHAPTER VII-3

BRICKS AND RELATED CLAY PRODUCTS MANUFACTURING [E]

There are about 520 manufacturers of brick plants in the U.S.[5] Most brick plants also produce other clay products like tile. Since clay is the principle raw material used, and clay is rather abundant in all of the U.S., no geographic preference is found for location of these plants.

The manufacture of bricks is rather simple. Different kinds of clays are ground, screened, mixed with water, extruded (pressed into shape) and dried in tunnel kilns. Other types of kilns include beehive, scove and shuttle kilns, but the tunnel kiln is the most popular. Typical size of a tunnel kiln is 12 ft. wide by 10 ft. high and 800 to 900 feet long for the newer kilns and 400 to 500 feet long for older tunnel kilns.[5] The temperature in the tunnel ranges from 1400°F to about 2200°F and varies with the structural properties of the brick desired. The exhaust gases from the tunnel are used as a drier for the fresh extruded brick before it enters the high temperature tunnel. Typical plant capacity is about 100 million bricks per year. There is no stack used at the end of a tunnel kiln to exhaust emissions at an elevation. There is no particulate emission associated with the tunnel kilns other than products of combustion which have been discussed in earlier chapters. The few beehive kilns still in use may use coal as a heat fuel which produces a distinct plume. Seventy-five percent of the brick manufacturers use natural gas as their heat source for the tunnel kiln. The remaining manufacturers use coal or resid oil. The major air pollution emission sources are the grinding, screening and mixing operations which emit dust. Most plants will control emission with baghouses from the grinding, screening and mixing operations.

The building brick is made by mixing one or two clays with water (10 - 25 percent water and 75-90 percent clays). About one ton of clay will yield one ton of finished brick. Operational time for these plants are usually 1 or 2 shifts per day and 5 days a week.

GAS FLOW RATE

The gas flow rates for those plants with control devices on the grinding, screening and mixing operations will range from 5,000 to 30,000 scfm depending on the size of the area which is ventilated. This range is typical with other mineral process catagories which utilize a crushing and screening operation. For modeling purpose use 15,000 scfm for plants with control equipment when specific fan data is not available.

The flow rate of the hot gases eminating from the tunnel kilns are low, about 1500 scfm.

GAS TEMPERATURE

The gas temperature will be ambient for the grinding, screening, and mixing operations.

For the tunnel exhaust the temperature will be near 200°F (no data were available).

GAS VELOCITY

Based on data from similar processes, the gas exit velocity for brick plants is estimated at 10 fps since baghouses will usually have a lowered wall instead of a stack for emission points.

The flow rate from tunnel kilns is about 10 fps and are not vented through a stack.

STACK HEIGHT

Baghouses usually sit alongside a plant and have an effective stack height of about 15 feet. Tunnel kilns also have a stack height of 15 feet.

CHAPTER VII-4

CALCIUM CARBIDE PLANT[c]

Of the 1.15 million tons of calcium carbide produced in the U. S. in 1965, 70% was used in the preparation of acetylene and the remaining 30% to prepare cyanamide. Calcium carbide is prepared by reacting quicklime (CaO) and carbon (coke, anthracite or petroleum coke) in an electric furnace at 2000 to 2200°C. The reaction proceeds according to the equation (Figure VII-4.1):

$$CaO + 3C + 111 \xrightarrow{heat} CaC_2 + CO \qquad \text{VII-4.1}$$

In 1950 there were 13 operating calcium carbide plants in the U.S. Because of the availability of natural resources many plants are located in northwestern New York. Most plants are equipped with continuous tapping furnaces which keep the reactants at the most efficient level in the reaction chamber. The capacity range of these furnaces is 5,000 to 25,000 kw-hr which producesup to 200 tons of carbide per day (Figure VII-4.2). The plants run continuously 3 shifts a day and 7 days a week. The major air contaminants are dusts: CaO, MgO, SiO_2, Fe_2O_3 and C. Most plants control emission with a high energy scrubber, baghouse or an electrostatic precipitator.[6]

GAS FLOW RATE

Only two plants were available for analysis of exhaust flow; the flow rates were 152,000 and 368,000 scfm (Table VII-4.1) for a 40 ton per hour and a 15 ton per hour plant respectively.[3] No accurate conclusion can be drawn from these few data. However, similar flow rates in excess of 100,000 scfm can be expected from calcium carbide plants.

GAS TEMPERATURE

The gas exit temperatures for the plants were 135 and 153°F. Exit temperatures are not expected to vary much from 150°F.

GAS VELOCITY

The gas exit velocity was 30 and 75 fps for the two plants.

STACK HEIGHT

Stack heights for the two plants were 70 and 95 feet. If no data are available use a height of 80 feet for calculations.

TABLE VII-4.1

Exhaust Gases From Calcium Carbide Plants [3]

Constituent	Input Rate tph	Exhaust Flow 1000 scfm	Exhaust Temp. ^{o}F	Stack Velocity fps	Stack Height ft	Stack Diameters ft	Operating Time	Control Equipment
$CaCO_3$	36.2							
Coal	13.7	152	135	33	70	4	Continuous	hood - wet scrubber
Coke	2.7							
CaO + Coke	22.6	368	153	75	95	4.75x4.75 4.75x5.00		
CaC_2 produced: 15.1 tph								

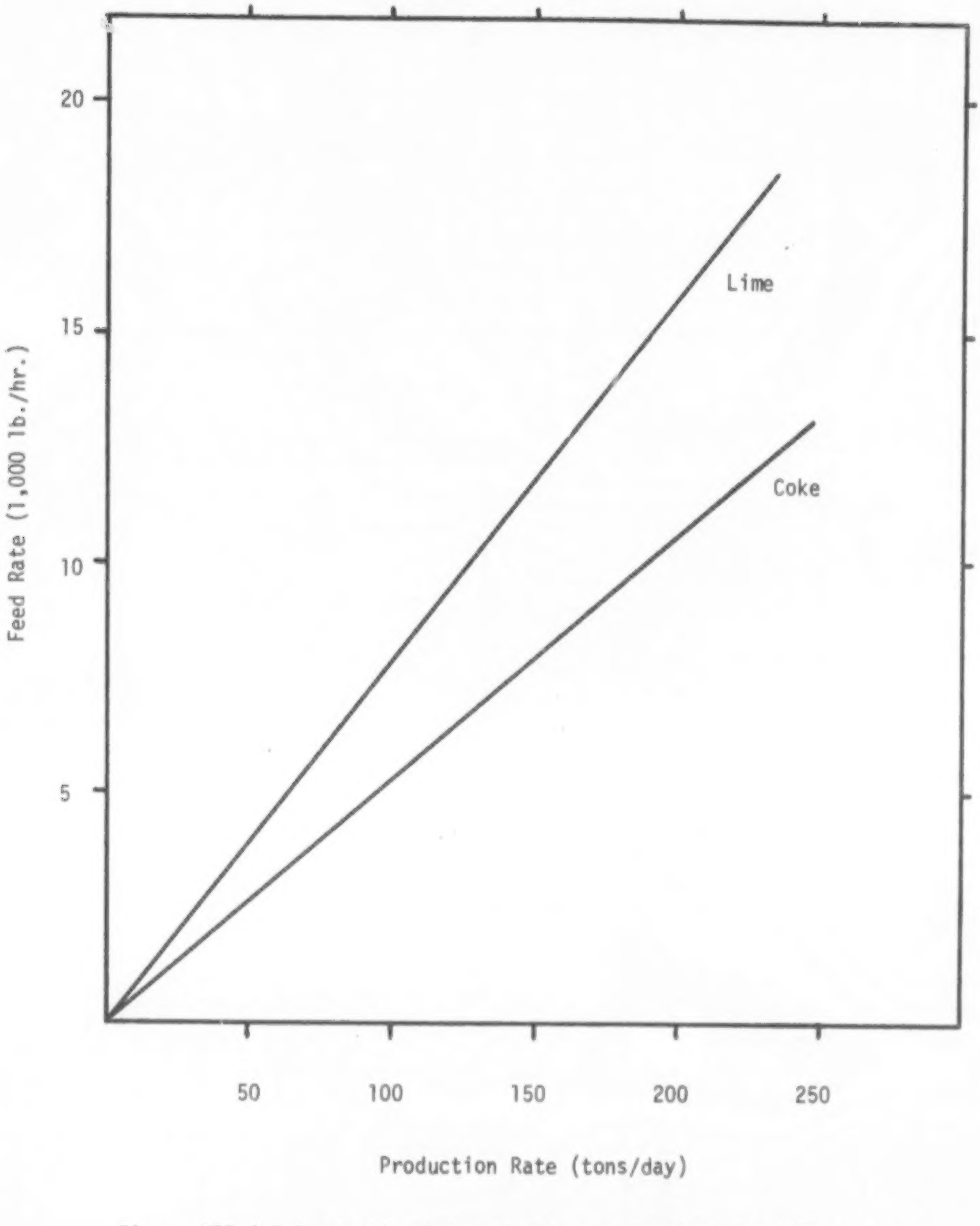


Figure VII-4.1 Production Rate of CaC_2 vs. Reactant Feed Rate

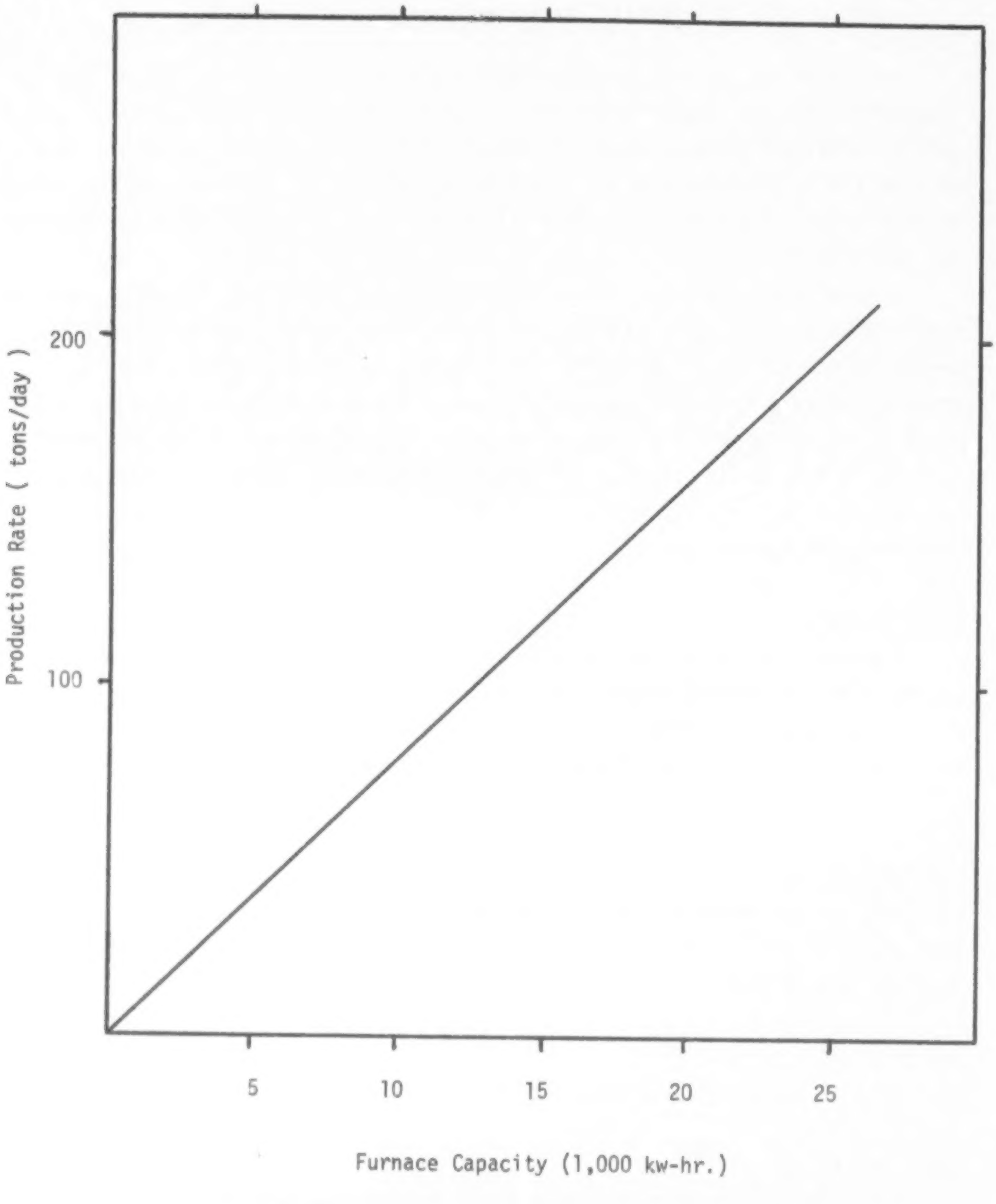


Figure VII-4.2 Production rates of CaC_2 in Electric Furnaces

CHAPTER VII-5

CASTABLE REFRACTORY PLANT^B

Refractories are used principally as heat shields in a variety of high temperature furnace applications like melting glass, steel or nonferrous metals, kilns and ceramic drying furnaces. Refractories are sold in the form of fire brick; silicon, magnesite, chromite, silicon carbide and aluminum silicate to name a few. Each type of refractory has unique properties which are applied for specific furnace use.

Typical plant capacity ranges between 30 and 50 tons per day, and plants are located in large metropolitan industrial areas of the country. Since the manufacturing operation is simply a drying and pressing operation, the input rate is the same as output rate.[3] Most plants use gas or oil fired tunnel kilns to dry the ceramic raw materials. The major air contaminant is dust especially from the dryer and processing (transport) operations. Baghouses, scrubbers and cyclones are used as abatement equipment. Refractory plants operate 5 days/week and 2 shifts per day.

GAS FLOW RATE

Exhaust flow rates from castable refractory plants ranged from 1,000 to 14,000 scfm for several driers. All driers had control equipment in use. Plant flow rates are consistent with other kiln drier applications. An average flow rate of 7,500 scfm should be used when no specific fan data are available (Table VII-5.1).

GAS TEMPERATURE

Exhaust gas temperatures from the drier ranged from 200 - 1,000°F with a mean of about 500°F. Exhaust gases from screening and crushing operation would be near ambient temperatures.

GAS VELOCITY

Exhaust gas velocities ranged from 7 to 76 fps with a mean of 35 fps.

STACK HEIGHT

Table VII-5.1 shows stack heights for several castable refractory plants. They range from 15 to 60 feet with an average of near 30 ft. For modeling purposes a stack height of 30 feet should be assumed.

TABLE VII-5.1

Exhaust Gases from Castable Refractory Manufacturing Processes[3]

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameters ft.	Operating Time
Kiln	200 lb./cyc.	1.77	605	6.9	30	2.5	32 hr./cyc., 260 cyc./yr.
	2000	2.11	873	26.0	30	1.4	
	2000	3.63	954	52.0	30	1.5	
	2000	1.32	954	15.0	45	1.5	
	1100	0.88	959	10.4	30	1.7	
	2800 lb./cyc.	7.97	846	13.5	48	4.3	92 hr./cyc., 25 cyc./yr.
	2800 lb./cyc.	7.19	846	16.1	60	4.3	92 hr./cyc., 25 cyc./yr.
	2880	1.83	880	32.7			
	2900 lb./cyc.	1.38	708	14.0	35	1.4	72 hr./cyc., 72 cyc./yr.
	6900 lb./cyc.	3.88	1032	57.5	35	1.5	72 hr./cyc., 72 cyc./yr.
	3500 lb./cyc.	0.90	998	14.5	35	1.1	9 days/cyc., 16 cyc./yr.
	3500 lb./cyc.	1.08	1034	18.0	35	1.1	9 days/cyc., 16 cyc./yr.
	1336	1.09	567	14.0	35	1.3	
	1336	0.82	951	18.0	35	1.3	

TABLE VII-5.1

Exhaust Gases from Castable Refractory Manufacturing Processes, Continued

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameters ft.	Operating Time
Kiln	13,800	14.26	640	45.3	21	2.6	220,000 gal./yr. of oil
	6,900	21.70	450	41.5	21	3.3	
	11,400	14.28	200	37.8	21	2.8	
	50,000	9.00	200	37.5	45	2 x 2 sq.	2 shifts/day, 5 days/wk.
Crushing and Handling	30,000	27.73	535	62.0	45	.83 x 1.3	8 hr./cyc., 280 cyc./yr.
	24,000	7.97	540	40.0	45	1.2 x 1.3	8 hr./cyc., 280 cyc./yr.
	12,000	0.18	540	3.0	15	1.2 x 1.3	8 hr./cyc., 280 cyc./yr.
Crucible Mix	1,000	1.54	540	16.6	22	1.6	8 hr./cyc., 280 cyc./yr.
Transport System	4,500	2.87	540	26.6	35	1.3 x 1.5	1.8 hr./cyc., 345 cyc./yr.
	4,500	3.16	540	26.6	35	1.3 x 1.5	1.8 hr./cyc., 345 cyc./yr.
Blending	10,000 (lb./bat.)	8.96	538	36.0	45	2.0	8 hr./cyc., 225 cyc./yr.
	3,500	4.92	540	76.0	32	3.0 x 2.0	12 hr./cyc., 275 cyc./yr.
	2,500	1.47	540	46.6	30	1.0	8 hr./cyc., 260 cyc./yr.

TABLE VII-5.1

Exhaust Gases from Castable Refractory Manufacturing Processes, Continued

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameters ft.	Operating Time
Grinding	1,100	1.14	546	26.6	30	1.0	2 hr./cyc., 250 cyc./yr.
	185	1.26	550	28.0	32	1.0	8 hr./cyc., 250 cyc./yr.
	2,400	1.28	540	28.0	32	1.0	8 hr./cyc., 250 cyc./yr.
	1,000	4.40	575	70.0	32	1.2	8 hr./cyc., 250 cyc./yr.
	1,600	2.45	540	53.5	32	1.0	6 hr./cyc., 250 cyc./yr.
	1,600	2.45	540	53.5	32	1.0	6 hr./cyc., 250 cyc./yr.
	250	2.09	545	45.8	32	1.0	8 hr./cyc., 250 cyc./yr.
	100	2.11	540	46.0	32	1.0	2 hr./cyc., 130 cyc./yr.
	300	1.46	540	31.7	32	1.0	4 hr./cyc., 90 cyc./yr.
	1,550	0.63	545	31.3	32	0.7	4 hr./cyc., 250 cyc./yr.
	120	0.58	545	46.6	32	0.5	4 hr./cyc., 250 cyc./yr.
Tunnel, Dryer, Carton Station and Bag Station	1,000 (lb./bat.)	12,000 cfm	50-110	56	25		300 batches/wk.

CHAPTER VII-6

CEMENT PLANT [B]

There are about 200 cement plants in the U. S. which make 500 million pounds of cement annually. Cement, of course, is the basic raw material for concrete, which is utilized in most every form of large construction of roads, buildings, bridges, etc. Cement plants are scattered throughout the U. S. since their basic material is the abundant limestone and other hard rock.

Portland cement is manufactured either by the dry or wet process, in large calcining kilns which are several hundred feet in length. The trend today is toward kilns over 400 feet in length which means increased throughput rates. To produce one barrel of cement weighing 376 pounds, approximately 600 pounds of raw materials (not including fuel) are required (Tables VII-6.1 and VII-6.2 and Figure VII-6.1).

Particulate matter is the primary emission from the manufacture of Portland cement (Figure VII-6.2). Most of the particulate is emitted from the rotary calcining kilns. Fuel requirements to generate heat for the kilns are about 1.2 million BTU/bbl. for those plants built prior to 1963. Newer plants require about 0.9 million BTU/bbl.[7] Fossil fuels commonly used include coal, oil and natural gas. Short dry process kilns with vertical suspension preheaters utilize 540,000 to 640,000 BTU/barrel, and grate preheater process kilns utilize approximately 600,000 BTU/barrel.[8] Although the wet-process kiln has a higher heat requirement than the dry-process kiln, the fuel consumption difference, in many cases, is partially offset by the heat consumed in the dryers preceeding the dry process kiln, whenever they are used. When preheaters are not used, the wet process requires more heat to drive off the 30 to 40 percent water in the slurry.

Most plants have some air pollution control equipment associated with the kiln emission source. Baghouses and/or mechanical collectors are commonly used to control dusts.[9]

GAS FLOW RATE

The exhaust gas flow rate from kilns follows a close relationship from plant to plant despite various configurations of the drying kilns (Figure VII-6.3 and Figure VII-6.4). The exhaust flow rate is about 0.75 scfm for each lb./hr. of cement produced by the wet process and 0.6 scfm for each lb./hr. for the dry process.

GAS TEMPERATURE

The range of exhaust temperatures from 22 wet process plants was 285 to 750°F with a mean of 425°F. For 11 dry process plants the temperatures ranged from 375 to 845°F with a mean of 555°F. For calculations assume 400°F for wet process plants and 550°F for dry process plants.

GAS VELOCITY

No data were available, but gas exit velocity for these plants is expected to be between 20 and 60 fps with a mean of 40 fps.

STACK HEIGHT

No data were available, but cement plants have a single large concrete stack extending 100 to 300 feet high. Assume 200 feet when data are not available.

TABLE VII-6.1

Exhaust Gasses from Wet Process Cement Manufacturing Plants[8]

Production Rate 1000 bbl./da.	Process Weight 1000 lb./hr.	Exhaust Gas Volume 1000 scfm	Exhaust Gas Temperature °F
19.44	486	371	450
10.56	264	205	550
8.88	222	217	750
9.192	230	144	385
3.98	99.5	98	363
5.0	125	129	290
4.5	112.5	97	320
2.2	55	51	550
7.5	187.5	285	350
5.6	140	176	355
2.5	62.5	87	385
1.9	47.5	54	450
3.475	86.9	109	330
3.9	97.5	59	285
7.1	177.5	148	343
6.25	156	109	525
7.6	190	253	460
6.86	171.5	211	450
3.6	90	79	547
2.8	70	133	352
8.3	208	170	390
11.4	285	230	500

TABLE VII-6.2

Exhaust Gases from Dry Process Cement Manufacturing Plants [8]

Production Rate 1000 bbl./da.	Process Weight 1000 lb./hr.	Exhaust Gas Volume 1000 scfm	Exhaust Gas Temperature °F
9.216	230	152	700
4.0	100	30	375
1.88	47	22	500
5.26	132	109	500
9.58	240	161	510
3.8	95	131	467
1.67	42	57	497
3.3	82	66	550
0.5	12	16	845
2.9	72	60	600
2.75	69	64	560

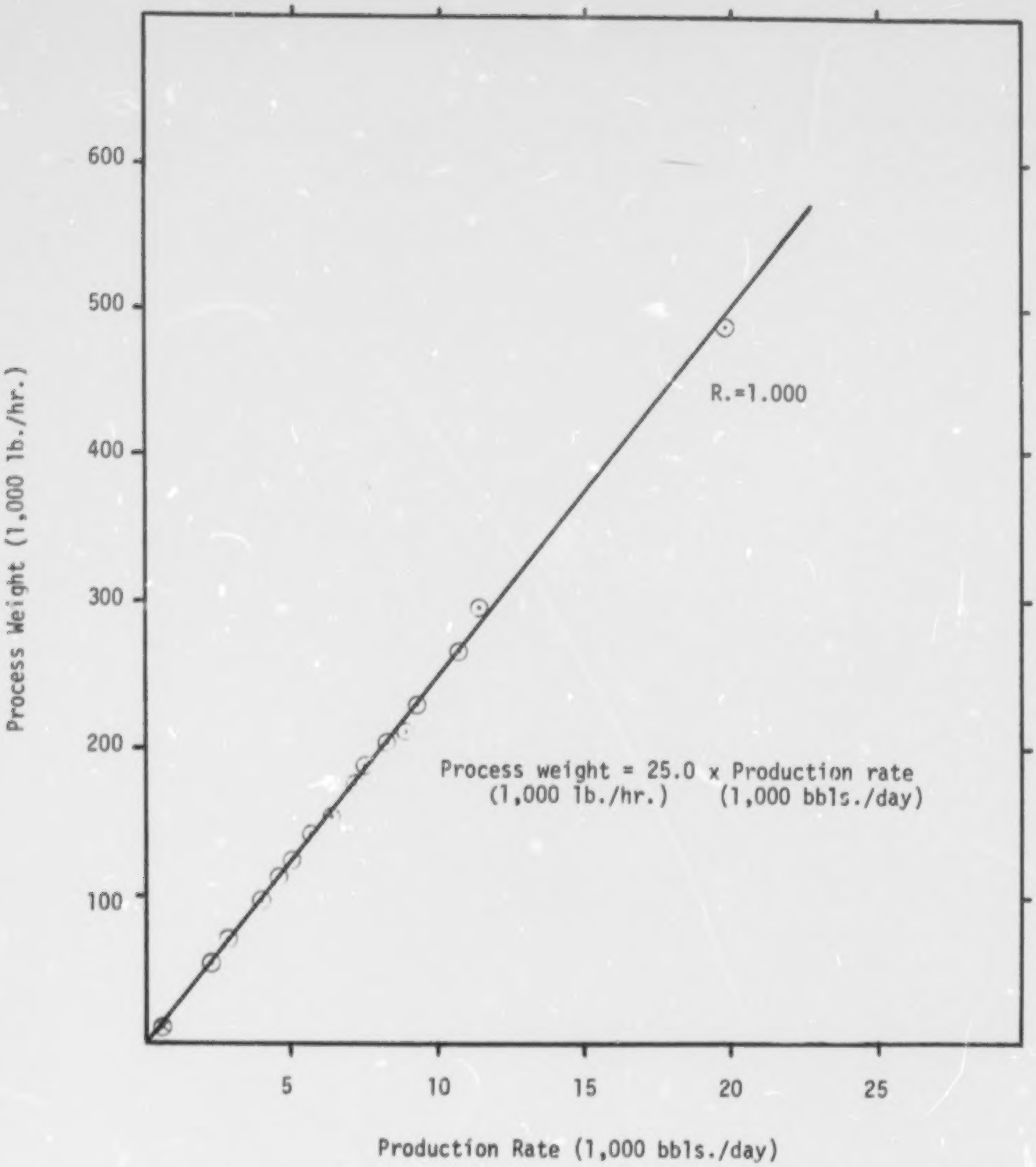


Figure VII-6.1 Process weights used in wet and dry cement manufacturing

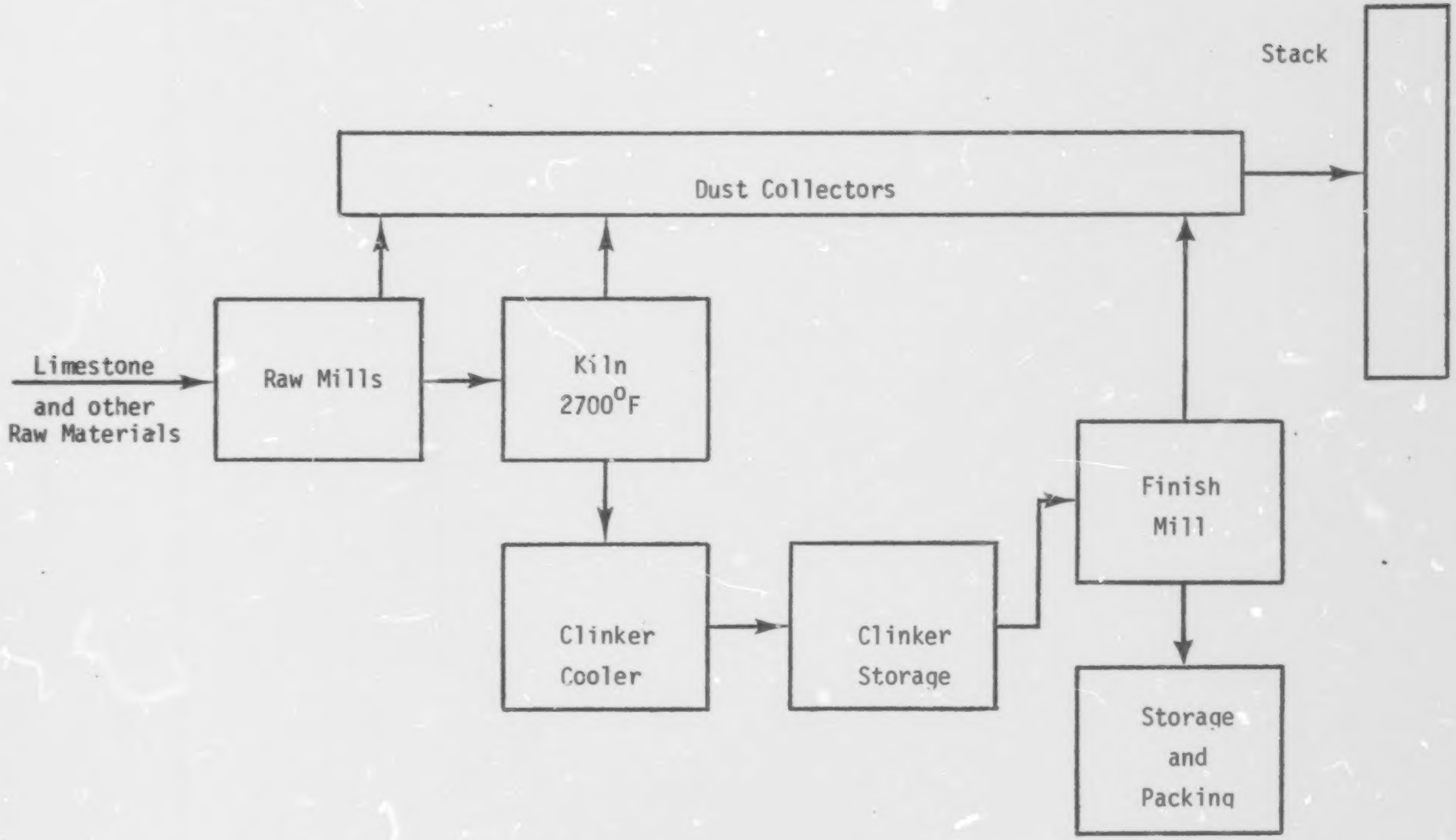

Stack
Dust Collectors
Limestone
and other
Raw Materials
Raw Mills
Kiln
2700°F
Clinker
Cooler
Clinker
Storage
Finish
Mill
Storage
and
Packing

Figure VII-6.2 Flow diagram of cement plant operations

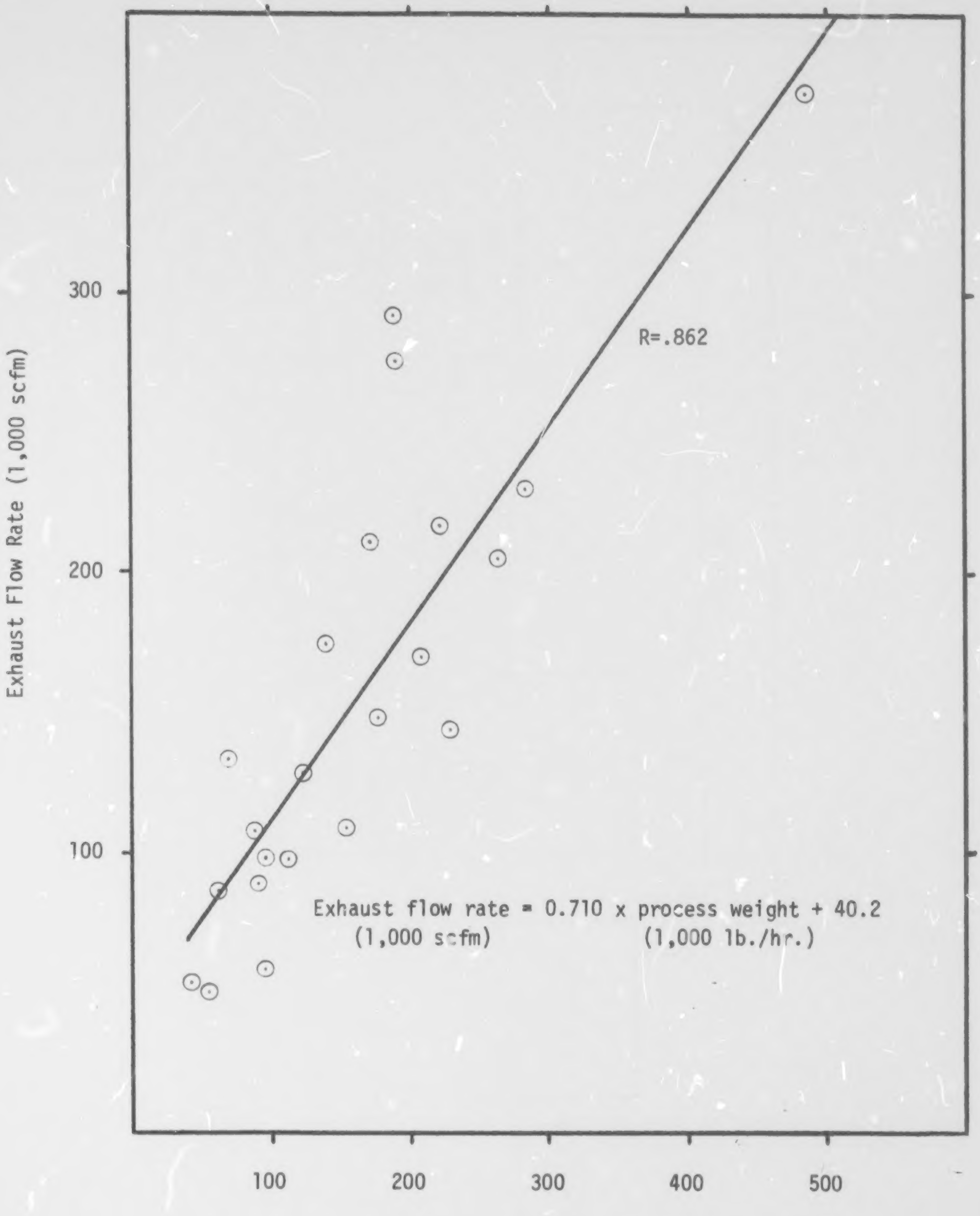


Figure VII-6.3 Exhaust flow vs. process weight for wet process cement manufacturing

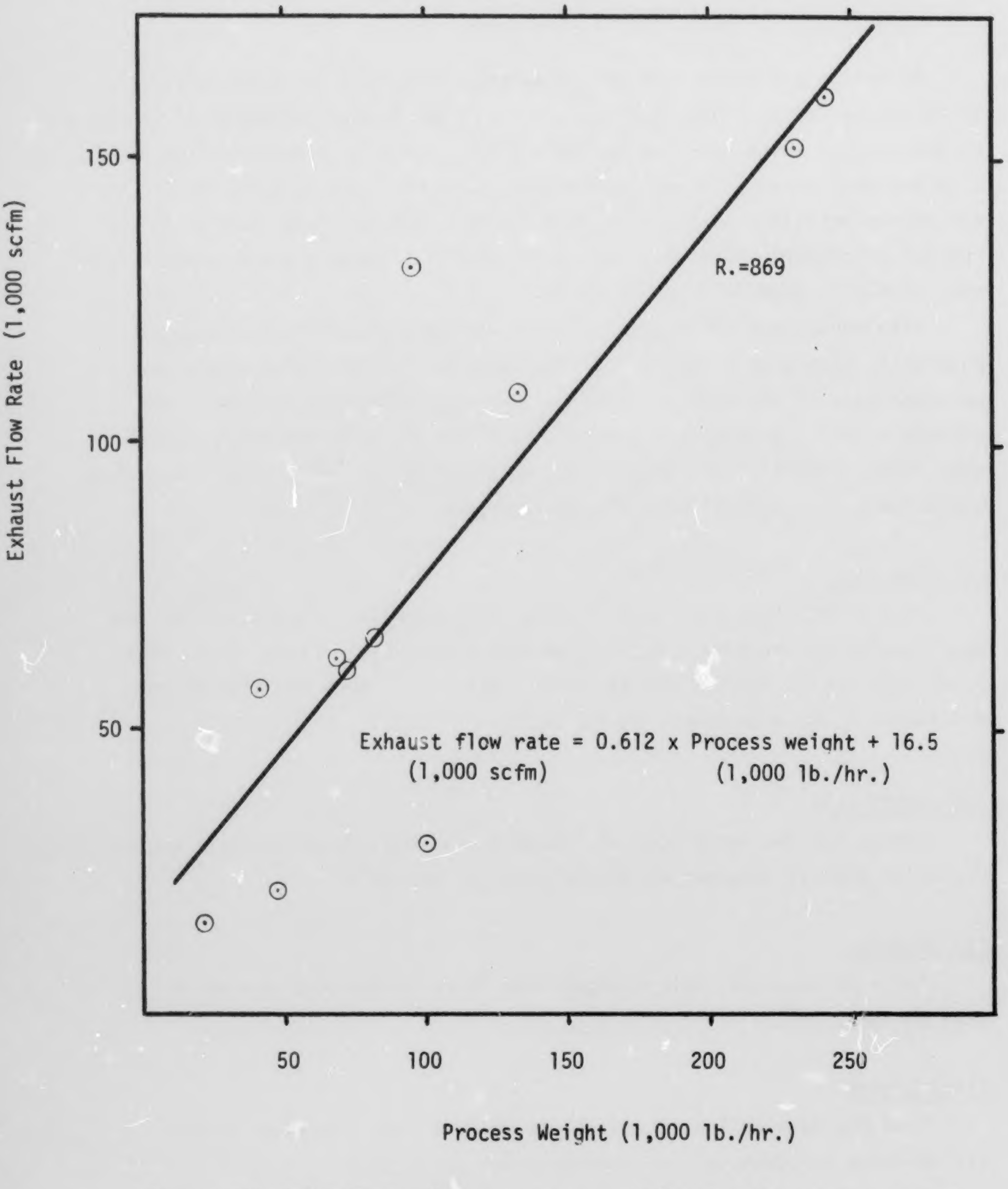


Figure VII-6.[4] Exhaust flow vs. process weight for dry process cement manufacturing

CHAPTER VII-7

CERAMIC CLAY PLANT [B]

In nearly all clays used by the ceramic industry, the basic mineral is kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$). Clays have the special property of plasticity or workability which make its use as a raw material applicable to the manufacture of glassware, pottery, china, porcelain, stoneware, and vitreous ware. By adding raw materials like borax, iron oxides, calcined bones and pearl ash special refractory properties can be obtained.[10] Typical plant capabilities vary widely -- from 50 to 5,000 lb./hr.

The manufacture of ceramic products involves conditioning basic raw materials, mixing or blending and forming. Drying and mixing operations generate most of the dust pollutants. Settling chambers, cyclones, wet scrubbers, and electrostatic precipitators are the main abatement devices, when used. However, most plants have no controls for pollutants. Operating times are 1 or 2 shifts/day and 5 days per week.

GAS FLOW RATE

Exhaust gas flow rate is determined by the collection system used and specifically by fan size. Typical exhaust flow systems range from 500 to 5,000 scfm for 10 ton/day plants (Table VII-7.1).[3] When fan size is not available 4,000 scfm should be assumed.

GAS TEMPERATURE

Except for the drier exhaust, temperatures will be essentially ambient. The drier exhaust temperature ranged from 130 to 420°F.

GAS VELOCITY

Gas exit velocity values ranged from 18 to 80 fps with a mean of near 50 fps.

STACK HEIGHT

From the data collected all stacks heights were less than 50 feet. For modeling purposes use an average stack of 30 feet.

TABLE VII-7.1

Exhaust Gases from Ceramic and Clay Manufacturing Processes[3]

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp °F	Exit Velocity fps	Stack Height ft.	Stack Diameter ft.	Operating Time
Drier	1600	21.4	60		45	3.5	5 hr./day, 300 days/yr.
	85	0.4	185		40	1.3	8 hr./ day, 54 days/yr.
	4.8	0.4	185		40	1.3	24 hr./day, 78 days/yr.
	6.66	0.03	130		22	0.25	
	115.8	2.2	170		40	1.2	
	704	1.5	420		45	1.2	16 hr./day, 50 days/yr.
	700	1.5	420		45	1.2	16 hr./day, 150 days/yr.
	85	10	90		40	1.0 x .83	8 hr./day, 100 days/yr.
Mixing	1000	1.0	70	58.3	17.5	-	8 hr./day, 5 days/wk.
			70		30	1.00	

TABLE VII-7.1

Exhaust Gases from Ceramic and Clay Manufacturing Processes, Continued

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameter ft.	Operating Time
Mixing		0.5	70	57.2	12	1.42	10 min./bat.
		7.8	70	26.6	30	2.50	3 min./bat.
		6.9	70	48.1	30	1.75	10 min./bat.
		4.1	70	43.4	30	1.00	
	400 lb./bat.	-	-	-	35	-	
	500 lb./bat.	2.1	78	29.6	18	1.25	
	500 lb./bat.	2.6	75	20.3	21	1.67	
Glazing	480	3.1	60	30	27	1.50	
	480	2.7	60	26.4	27	1.50	
	3000	-	60	18	25	-	
Convey & Cleaning	3000	5.5	80	35	27	1.83	
	3000	10.3	76	79	50	1.67	
	3000	9.7	80	75	50	1.67	

TABLE VII-7.1

Exhaust Gases from Ceramic and Clay Manufacturing Processes, Continued

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameter ft.	Operating Time
Furnace	800	19.3	130		46	6.0 x 1.0	15 hr./day, 250 days/yr.
	800	21.3	130		46	6.0 x 1.0	15 hr./day, 250 days/yr.
	800	22.3	115		42	3.4	24 hr./day, 20 days/yr.
	800	22.2	116		42	3.4	24 hr./day, 20 days/yr.

CHAPTER VII-8

Clay and Fly Ash Sintering Plants [D]

There are less than 5 fly ash sintering plants in the U. S. which operate full scale and on a continuous basis with a throughput rate of about 200 tons/hour. The basic raw material is fly ash from coal fired power plants. The fly ash is first pelletized into spherical bodies then placed on a traveling grate (8 ft. wide and 98 ft. long) where the fly ash balls are fused together. All units are fired with natural gas at a bed temperature of 1900 - 2300°F.

Fly ash products are, at present, limited to use as an aggregrate in structural concrete or building blocks. A small amount of all fly ash produced from coal combustion goes through a sintering process. Full scale operating plants are located in Anodazo, N.Y., Pittsburgh, Pa., and Detroit, Mich. All three of these plants use control equipment (precipitator or baghouse) because of a high fine particulate emission. No information was available on natural gas usage at these installations. Plants operate continuously 24 hours per day and 7 days a week.[11,12]

No information about clay plants was obtained, but one source indicated that there is little difference between clay and fly ash sintering plants.[11]

GAS FLOW RATE

Specific fan sizes from these three installations were not known but were estimated at about 10,000 to 20,000 scfm. The product sizing is controlled (with the use of dampers) by the amount of over fire air passing through the steel belt.

GAS TEMPERATURE

The gas temperature at the stack exit point was estimated at 450°F for the sintering plants.

GAS VELOCITY

No information was secured concerning exit velocities, however, 20-40 fps is expected. For modeling purpose use an exit rate of 30 fps.

STACK HEIGHT

The stack heights for the three units were estimated at 150-200 feet.

CHAPTER VII-9

CONCRETE BATCHING PLANT [c]

Concrete batching plants store, convey, measure and discharge the ingredients for making concrete to mixing or transportation equipment. Concrete is used in a vast number of construction applications like highways, office buildings, water dams, bridges and foundations. Concrete plants are located throughout the U. S.; the Washington, D.C. area alone has over 200 concrete contractors.

There are basically two kinds of concrete batch plants, wet and dry batching. Both will be analyzed together even though wet plants will not emit as much dust as the dry batching plants. The major pollutant is dust which is generated during unloading of cement, gravel and sand, transport and filling operations. The recommended air pollution abatement equipment is the baghouse; however, most plants do not have any control devices. Typical operating times are 8 hours per day and 5 days per week. Figure XII-9.1 is a sketch of the plant.

GAS FLOW RATE

Exhaust gas flow rate (from plants which have control devices) is entirely dependent on the system configuration and fan size. The recommended collection rate is 6000-7000 scfm.[2] From the data collected the exhaust flow ranged from 250 - 5000 scfm.[3] For calculation purposes use an average of 5000 scfm for all plants with control and 300 scfm for plants with no control equipment (Table VII-9.1).

GAS TEMPERATURE

Exhaust gas temperature will be ambient since there is no combustion associated with this process.

GAS VELOCITY

The gas velocities are low because few plants control dust. The exit velocity for these plants with no control equipment will, by natural convection, be 3 to 10 fps. Those plants which control dusts have an exit velocity of about 15 to 30 fps.

STACK HEIGHT

Stack heights ranged from 26 to 50 feet with a mean of about 35 feet. For modeling purposes this process should be treated as an area source.

TABLE VII-9.1

Exhaust Gases from Concrete Batching Plants[3]

Input Rate lb./batch	Exhaust Flow scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Operation Time	Control Equipment
-	250	Ambient		42		Bag filter
-	250	Ambient		50		Bag filter
3300	600	70		40	1 min./batch, 50 bat./day	
3300	600	70	25	40	1 min./batch, 50 bat./day	
8000	5000	70		26	0.5 hr./batch, 16 bat./day	Bag house

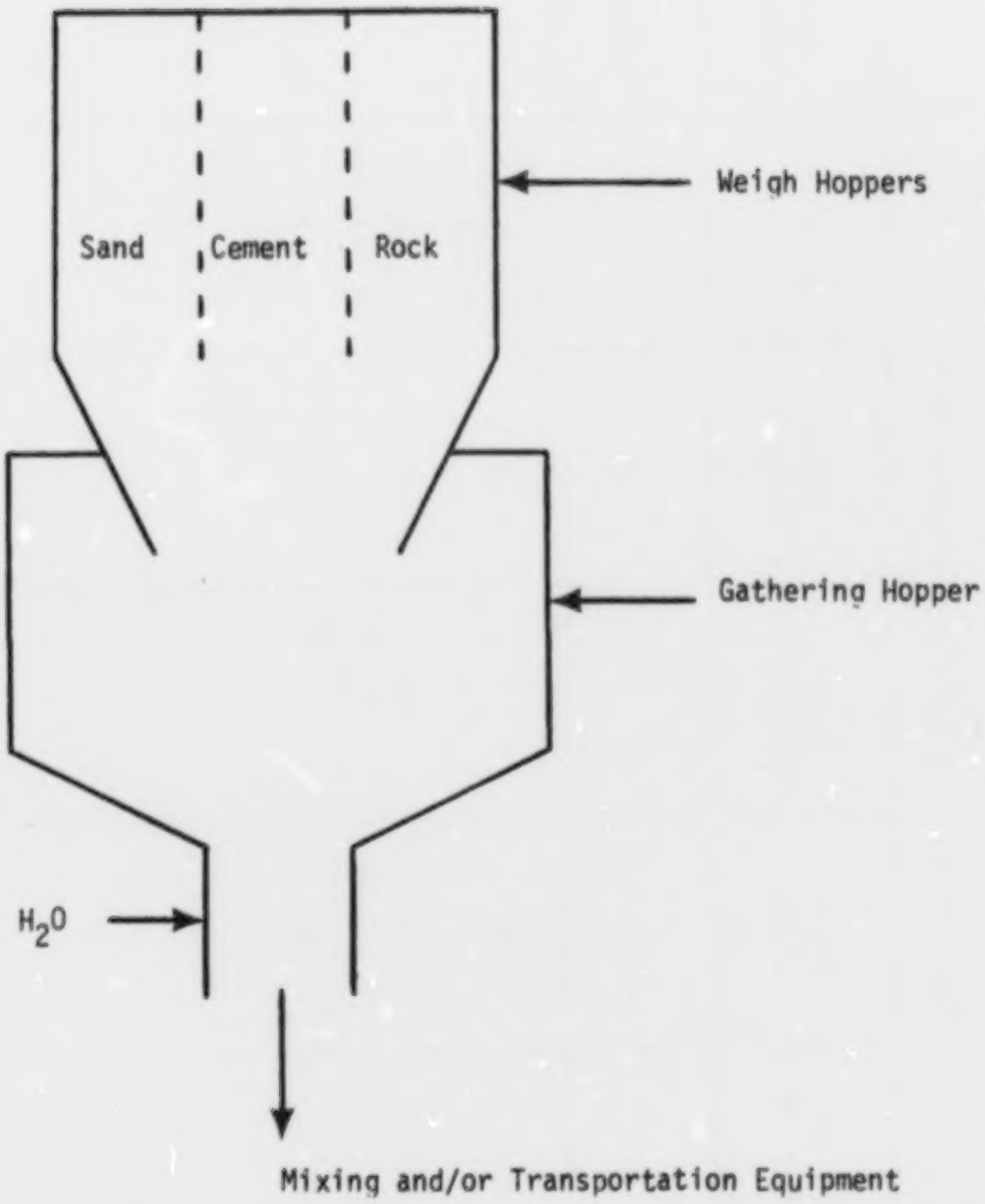

Weigh Hoppers
Sand
Cement
Rock
Gathering Hopper
H_2O
Mixing and/or Transportation Equipment

Figure VII-9.1 Flow diagram of a concrete batching plant

CHAPTER VII-10

FIBER GLASS PLANT [B]

About 50 percent of the manufactured fiber glass is used for thermal and acoustical insulation and about 35 percent is used for textiles. The basic ingredients for continuous filament fiber include silicon dioxide, calcium oxide, aluminum oxide, and boric oxide. Increasing widespread uses continue to make the demand favorable. Glass marbles are melted then extruded through small holes (forming operation) making a filament. The filament travels through a curing oven before it is packed. Plant size is determined by the number of lines or forming and curing machines. Since the raw materials for the process are only changed in form, one pound of ingredients will yield one pound of glass fiber material. Special properties like strength, elongation and durability are controlled by the addition of various basic ingredients. The major air pollutants from fiber glass manufacture are glass fiber particulates and phenol resins. Cyclones and fume incinerators are the common types of air pollution abatement equipment.

GAS FLOW RATE

Exhaust gas flow rate, as well as other pertinent data, are listed in Table VII-10.1.[3] Some plants only indicated data from one phase of the operation. The two critical phases are forming and curing operation. Figure VII-10.1 displays exhaust flow rate as a function of process weight for both operations. The figure indicates that flow rate is dependent on the individual configuration used and not on the process weight. All plants used some form of air pollution control equipment.

GAS TEMPERATURE

Exhaust gas temperatures ranged from 200 - 250°F for the curing operation. The forming operation temperature ranged from 70 - 160°F. For modeling, use 200°F for both curing and forming operations.

GAS VELOCITY

Stack gas velocities ranged from 5 - 41 fps for all operations of the fiber glass plant. The average velocity for the 7 plants was about 40 fps.

STACK HEIGHT

The stack heights reported for three plants ranged from 30 - 71 feet. For modeling use a stack height of 60 feet.

TABLE VII-10.1

Exhaust Gases From Fiber Glass Plants.[3]

Production Step	Input Rate	Exhaust Flow 1000 cfm	Exhaust Temp. °F	Stack Velocity fps	Stack Height ft.	Stack Diameters ft.	Operating Time	Control Equipment
Forming	550 lb./hr.	16.8	200	36	71		24 hrs./day 7 days/wk.	Fume Incinerator
	2,500 lb./bat. 100 lb./hr.	2.5	70	5	34			Hydrated lime Asbestos Batch Process
	550 lb./hr.	16.8	200	36	71		24 hrs./day 7 days/wk.	
	10,000 lb./day 41.5 lb./hr.	65.0	160		40	5.42 x 5.83	Continuous	
	5,000 lb./day	38.0	160		40	5.16 x 5.59		
		15.0	160		40	5 x 6		
Curing	2,000 lb./bat.	0.4	200		30		10 min./batch 20-28 bat./wk.	
	10,000 lb./day 41.5 lb./hr.	10.0	250		45	1.75	Continuous	
	5,000 lb./day	2.0	250		45	1.50		
		2.0	250		45	1.00		
Machining	500 lb./hr.	8.4	70	41	42		24 hrs./day 7 days/wk.	Cyclone

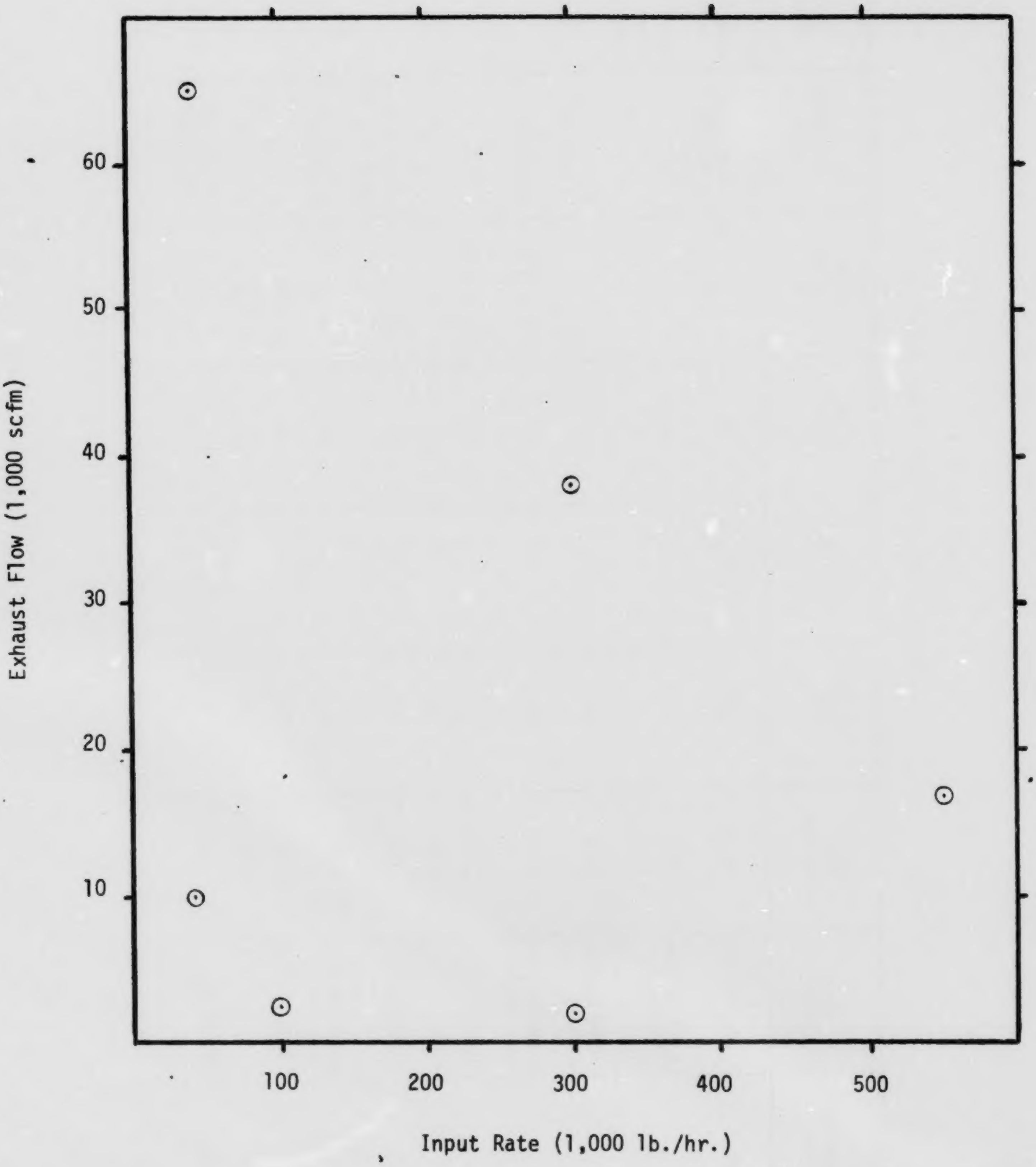


Figure VII-10.1 Exhaust flow vs. input rates for various fiber glass plants

CHAPTER VII-11

GYPSUM PLANT[B]

Gypsum ($CaSO_4.2H_2O$) is a mineral that occurs in large deposits throughout the world. Calcination of gypsum is performed in large kilns (10-25 tons) at temperatures up to 190°C. Between 120 and 150°C, first settle plaster is formed which is mixed with sand or wood pulp and sold as gypsum plaster. Heating to 190°C forms second settle plaster ($CaSO_4$) which is used in the manufacture of gypsum products such as plasterboard. A common gypsum plant capacity is about 500 tons/day and plants are located in almost every state. Plants operate like other mineral products industries, about 16 hours/day and 5 days a week. Operational times, of course, depend on product demand. When more material is needed, longer work hours are ordered.

The major air pollutant is fine particulates from the drying kiln. However, other particulate emission sources include the crushing, screening, and transport system. All of the plants will use some form of a pollution abatement device such as scrubbers (the most common), baghouses or cyclones.

GAS FLOW RATE

Exhaust gas flow ranged from 40,000 to 48,000 scfm (from the drier) for plants with a capacity of 500 tons/day.[3] Of the three plants for which relevant data were obtained, two had control systems for crushing, grinding, or screening operations. The data are presented in Table VII-11.1.

GAS TEMPERATURE

Exit temperatures of flue gas from the drier were 129°F and 220°F for the two plants. Temperatures from the other processes were mainly ambient but reached a high of 146°F. When data are not available, use 150°F.

GAS VELOCITY

Gas velocity from various operations was relatively constant at 50 - 65 fps. When data are not available assume 50 fps.

STACK HEIGHT

Stack heights ranged from 45 - 106 ft. For modeling purposes 75 feet is recommended.

TABLE VII-11.1

Exhaust Gases From Gypsum Plants[3]

Production Step	Input Rate	Exhaust Flow 1000 scfm	Exhaust Temp. ^{o}F	Stack Velocity fps	Stack Height ft.	Stack Diameters ft.	Control Equipment
Drier	480 tpd 37,500 lb/bat	48.5	220	65	106	4	
Drier	500 tpd	40.6	129	60	57	4	
Screening		3.9	82		45	1.5	
Storage & Transfer		31.5	146	54	76	3.5	Electrostatic Precipitator
Cutting Board		6.3	84	51	60	16	

CHAPTER VII-12

LIME PLANT[c]

The annual production rate of lime products in 1964 was over 500 million tons produced from over 100 plants scattered throughout the country. Typical plant sizes range from 50 to 650 tpd. About 60 percent of the quarried limestone is used for concrete agregate; 20 percent is used for cement manufacture; and the remaining 20 percent is used for soil additives, chemical and metallurgical industry constituents, sugar production, pulp and paper production and reagents for the treatment of both water and air pollution.

Raw material used in lime production is the abundant hard rock-limestone ($CaCO_3$ + some impurities). Lime manufacturing plants will vary in the relative emphasis given to potential products, whether the product is used for commercial sale or captive use and the type of kiln used (verticle, rotary, open). The manufacturing process includes obtaining the rock, crushing, screening and burning the crushed rock in large kilns (calcination) to produce calcium oxide. The product may then be packaged for sale or conveyed to a lime hydrator to produce slaked lime (calcium hydroxide) which is then sized and packed in 50-lb. paper bags for distribution. (Figure VII-12.1) The reactions involved in these processes are:

$$\text{Calcining:} \quad CaCO_3 \longrightarrow CaO + CO_2$$

$$\text{Hydrating:} \quad CaO + H_2O \longrightarrow Ca(OH)_2$$

Plants usually operate continuously 24 hours a day for 6 or 7 days a week.

The major air pollution problem from lime production is particulate emissions from the kiln drier. Other emission points include the crushing and screening operations, transport corridors and final packaging. Most plants will use primary collectors (mainly cyclones) as air pollution control devices for kiln emissions. Vertical kilns have a low capacity (7-15 tpd) and are about 10-24 feet in diameter and 35-75 feet in height. Vertical kilns used by the alkali and sugar industry are sealed because of the need for CO_2 and present no air pollution problem. Coal fired and gas fired open kilns do present an air pollution problem but are of small capacity and are becoming obsolete.

Rotary kilns have capacities which exceed 500 tpd. Typical rotary lime kilns vary in size from 6 to 11-1/2 feet in diameter and from 60-400 feet in length though 150 feet is a common length. Various fuel/lime ratios are presented in Table VII-12.1 to show process weights and exhaust flow.[16]

About 60 percent of the lime kilns used evaluated pulverized coal; 28 percent used natural gas; 6 percent used oil and the remainder used combinations of fuels. Figure VII-12.2 shows the heat input requirements for various size plants, using rotary kilns and a fuel lime ratio of 1.0:3.37.[10]

GAS FLOW RATE

Gas volumes from 7 kilns ranged from 19,000 - 62,000 scfm after the collector with a mean value of 40,000 scfm. (Table VII-12.2).

GAS TEMPERATURE

Exhaust gas temperatures ranged from 350 to 522°F with a mean of about 450°F before the collector system. The temperature drop across the collector system was about 150°F. The exit temperature after the scrubber was about 170°F.

GAS VELOCITY

The gas exit velocity ranged from 25 to 58 feet. For modeling use 35 fps.

STACK HEIGHT

The stack heights were 250 and 400 feet. For modeling use 300 feet.

TABLE VII-12.1[16]

Process Weights for Pulverized Bituminous Coal Fired Rotary Kilns

Fuel/lime ratio lb./lb. (a)	Exhaust Gas Flow cf/ton of lime
1/1.4	203,500
1/2.0	146,200
1/3.0	101,500
1/4.0	79,200
1/5.0	66,100
1/6.0	57,000

(a) Bituminous coal with 13,500 BTU/lb.

TABLE VII-12.2

Exhaust Gases From Lime Plants[13,14]

Production Rate tons/day	Input Rate 10^6 BTU/hr.	Exhaust Flow	Exhaust Temp.		Stack Velocity fps	Stack Height	Stack Diameters	Control Equipment
			Before	After				
335 (76% aval. CaO)	140	62,000 cfm	350	165				Scrubber
200	95							
120		52,000 29,000	462	176	55			Scrubber
150		48,000 40,000	522	165	34			Scrubber
120		23,000 19,000	400	152	25			Scrubber
		45,000 25,000	410	170	58			
		52,088	476					
-		-	-		-	250	16	
-		-	-		-	400	15-1/2	

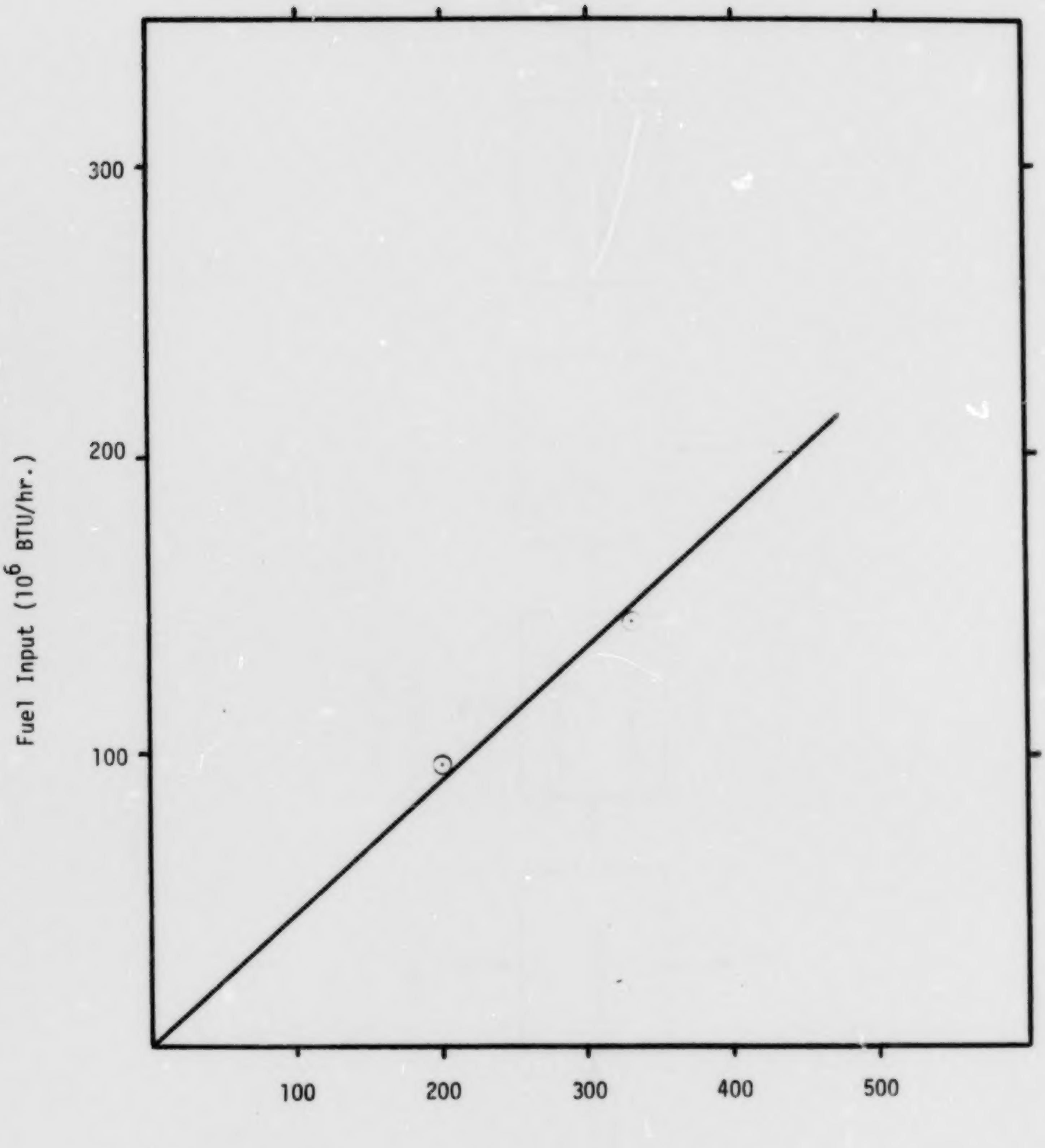


Figure VII-12.2 Heat Input for Lime Kiln

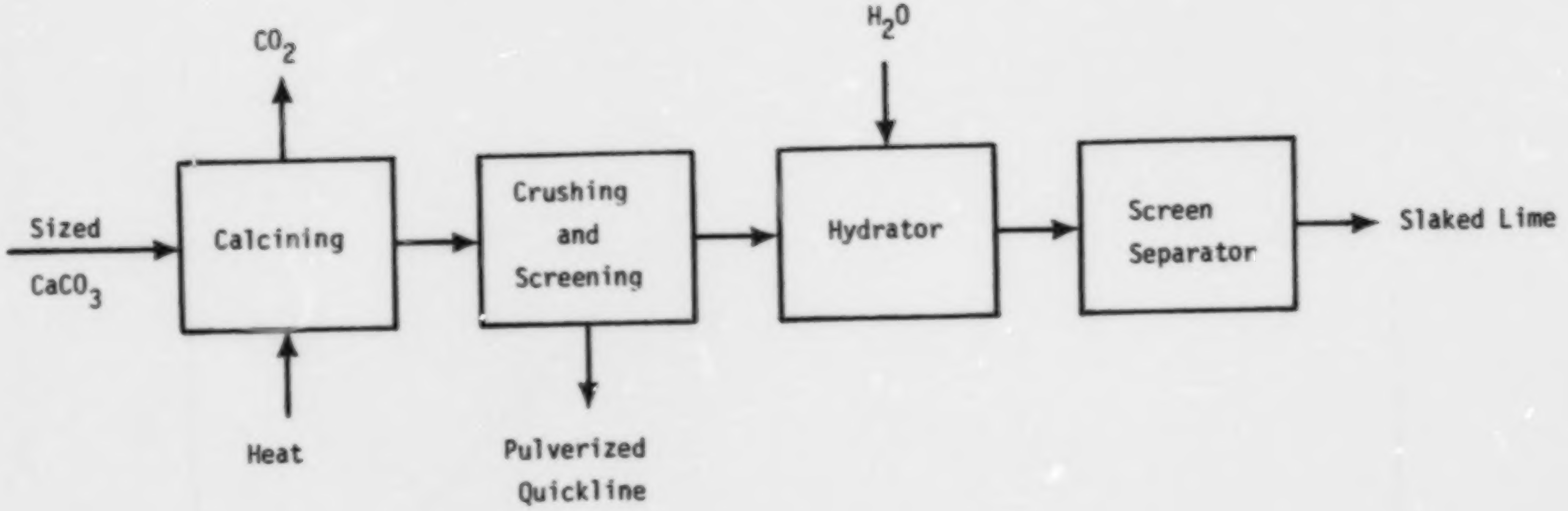

CO_2
H_2O
Sized
$CaCO_3$
Calcining
Crushing and Screening
Hydrator
Screen Separator
Slaked Lime
Heat
Pulverized Quickline

Figure VII-12.1 Flow diagram for a Lime processing plant

CHAPTER VII-13

PERLITE PLANT[B]

Perlite is a glassy, volcanic rock arranged by nature into small spherical bodies. Chemically, perlite consists of silicon and aluminum combined as natural glass with water of hydration. When the perlite is heated, the water escapes causing the spheres to expand and form a low desnity material (2-15 lb./ft.^{3}).

About 90 percent of all manufactured expanded perlite is used as an aggregate in plaster and concrete. Perlite ore deposits are mainly located in California and six other Rocky Mountain States, however expansion plants are located throughout the U. S. A plant for the expansion of perlite consists of a receiving and feeding device, an expansion furnace, a product classification system anda packing line (Figure VIII-13.1). Vertical furnaces, horizontal furnaces and horizontal rotary furnaces may be used to expand perlite ore. Essentially all perlite furnaces are fired with natural gas. The natural gas rate, amount of excess air and ore feed rate are governed to provide a furnace temperature, gas flow rate and material residence time which will yield a product of the desired density. Perlite plants usually operate continuously 20 hr./day and 5 days per week.

The major air pollutant is fine expanded perlite particles suspended in the flue gas which escape the controls. Most plants use control devices such as cyclones; some use baghouses. If one cyclone is not sufficient to abate the dust, two or more are commonly used in series for control. The furnace temperatures range from 1450 to 1300°F, but flue gases are cooled (to protect controll equipment) to about 200-250°F. Dilution air is commonly employed to reduce flue gas temperatures.

GAS FLOW RATE

Exhaust gas flow rates from perlite plants are governed by the furnace design and control system configuration more than production rate and are quite similar from plant to plant (Table VII-13.1). Flow rates from 4 plants ranged from 3500 scfm to 6400 scfm with an average near 5000 scfm for a 2000 lb./hr. plant.

GAS TEMPERATURE

Exhaust gas temperatures from the limited amount of data ranged from near ambient to 360°F with a mean of near 210°F. Use 200°F when data are not available.

GAS VELOCITY

Gas exit velocity ranged from 30 to 50 fps for four data points with an average of 40 fps. Stack diameters of about 3 feet are common.

STACK HEIGHT

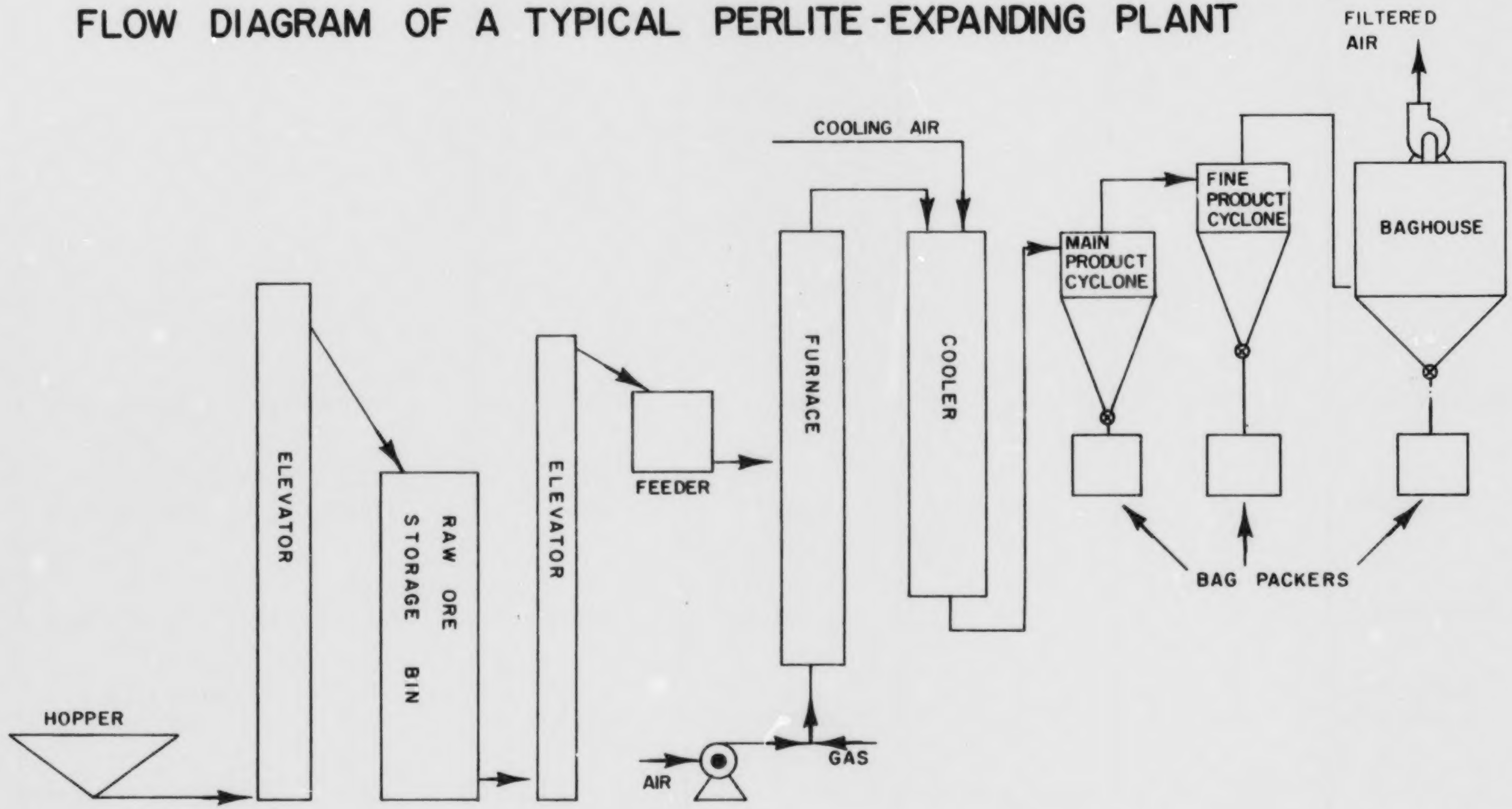
One plant had its control unit mounted on the ground and had a stack height of only 17 feet. Other stack heights ranged from 49 to 55 feet. Fifty feet should be used for modeling purposes.

TABLE VII-13.1

Exhaust Gases from Perlite Ore Expansion [3]

Production Rate	Operation Time	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Control Equipment
16 - 800 lb. batches/day		3.500	Ambient	50	17	Bag Dust Collector
2000 lb./hr.	20 hr./day, 5 days/wk.	6.100	205	32	49	Two Cyclones
2500 lb./hr.	20 hr./day, 5 days/wk.	6.400	360	43	55	Bag Houses
2500 lb./hr.	20 hr./day, 5 days/wk.	4.000	130	31	50	Four Cyclones

FLOW DIAGRAM OF A TYPICAL PERLITE-EXPANDING PLANT


FILTERED AIR
COOLING AIR
HOPPER
ELEVATOR
RAW ORE STORAGE BIN
ELEVATOR
FEEDER
FURNACE
AIR
GAS
COOLER
MAIN PRODUCT CYCLONE
FINE PRODUCT CYCLONE
BAGHOUSE
BAG PACKERS

CHAPTER VII-14

MINERAL WOOL PLANT [A]

The general product classification known as mineral wool was formerly divided into three catagories: slag wool, rock wool, and glass wool. Today slag wool and rock wool are no longer manufactured separately. Instead, a combined product made of slag wool and rock wool is called mineral wool.

Mineral wool is manufactured by a molten process in a cupola using blast furnace slag, silicon rock and coke (Figure VII-14.1). It is used mainly for domestic insulation in residential homes. Plants tend to be located near a source of slag such as a steel plant. Mineral wool plants operate 24 hours per day and 5 days a week. The major source of pollution is the cupola. Air contaminants are particulates, sulfur oxides and organic mists from the binder. Typical plant capacity is about 50 tpd. Essentially all raw materials are converted to mineral wool; therefore, no input-output curve is offered. Common control devices include baghouses, cyclones, scrubbers and afterburners. Most plants will use as minimum either a baghouse, cyclone or scrubber to abate particulate emissions.

GAS FLOW RATE

Exhaust gas flow rate for the cupola ranged from 4,510 scfm to 4,760 scfm for about a 4,000 lb./hr. cupola.[3] One author recommends exhaust requirements of 5,000 to 7,000 scfm for the same size unit.[2] Exhaust gas data are displayed for 25 tests (some made on the same line) on the cupola, reverberatory furnace, blow chambers, curing ovens, coolers and conveyor system (Figure VII-14.2).

The blow chamber cools molten material into fibers by sucking air through a belt which transports the molten product. A recommended minimum ventilation of 20,000 scfm for a 4,000 lb./hr. process has been suggested. The range for observed data was 11,000 to 28,000 scfm (Table VII-14.1).

Stack gas flow rate from curing ovens ranged from 1,642 to 8,000 scfm with a mean of about 5,000 scfm.

Exhaust flow from the coolers ranged from 1,860 to 16,000 scfm with a mean of about 9,000 scfm.

GAS TEMPERATURE

Table VII-14.1 indicates data on temperatures found for each phase of mineral wool manufacture. The cupola exhaust temperature averaged about 310°F (after the control device); blow chambers are kept at 200°F for process conditions, thus the exit gas temperature averaged about 190°F. The curing oven temperatures averaged about 300°F while the mineral wool cooler exhaust averaged about 200°F. Where specific data are unavailable, 250°F should be assumed.

GAS VELOCITY

Gas velocity on one plant which had 3 cupolas ranged from 10 to 40 fps. A mean of about 25 fps may be assumed.

STACK HEIGHT

The stack heights were all below 65 feet as can be seen from Table VII-14.1. For modeling purpose use 50 feet.

TABLE VII-14.1

Exhaust Gases from Rock Wool Manufacturing[3]

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Control Equipment	Operation Time
Cupola	3525	4.55	309				
	4429	4.55	314				
	3625	4.76	338				
Reverberatory Furnace	3050	2.74	625				
Blowchambers	3525	11.10	196				
	3625	15.76	160				
	3525	28.73	188				
	3700	19.75	167			Lint Cage	
	4120	15.40	200			Wet Scrubber	
Curing Ovens	3525	4.74	326				
	3625	4.86	353				
	3050	1.64	310				
	5180	8.0	200			Catalytic Afterburner	
	3500	4.87	270			Direct Flame Afterburner	

TABLE VII-14.1

Exhaust Gases from Rock Wool Manufacturing, (Continued)

Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Control Equipment	Operation Time
Coolers	3525	1.85	128				
	3700	8.50	273				
	3050	16.70	170				
	3050	8.98	298				
Cupola	1780 lb./cupola	11,35	400	38.2	5	Cyclone	24 hr./day, 5 days/wk.
	7490 lb./batch (4980 lb./hr.)	4,40	400	28.0	50	Cyclone	15 min./batch 96 bat./wk
Conveying System	7500	22,00	100	21.7	65	Scrubber	24 hr./day 6 days/wk.
	7480 lb./batch (4980 lb./hr.)	4,40	400	11.7	42	Cyclone	15 min./batch 96 bat./wk

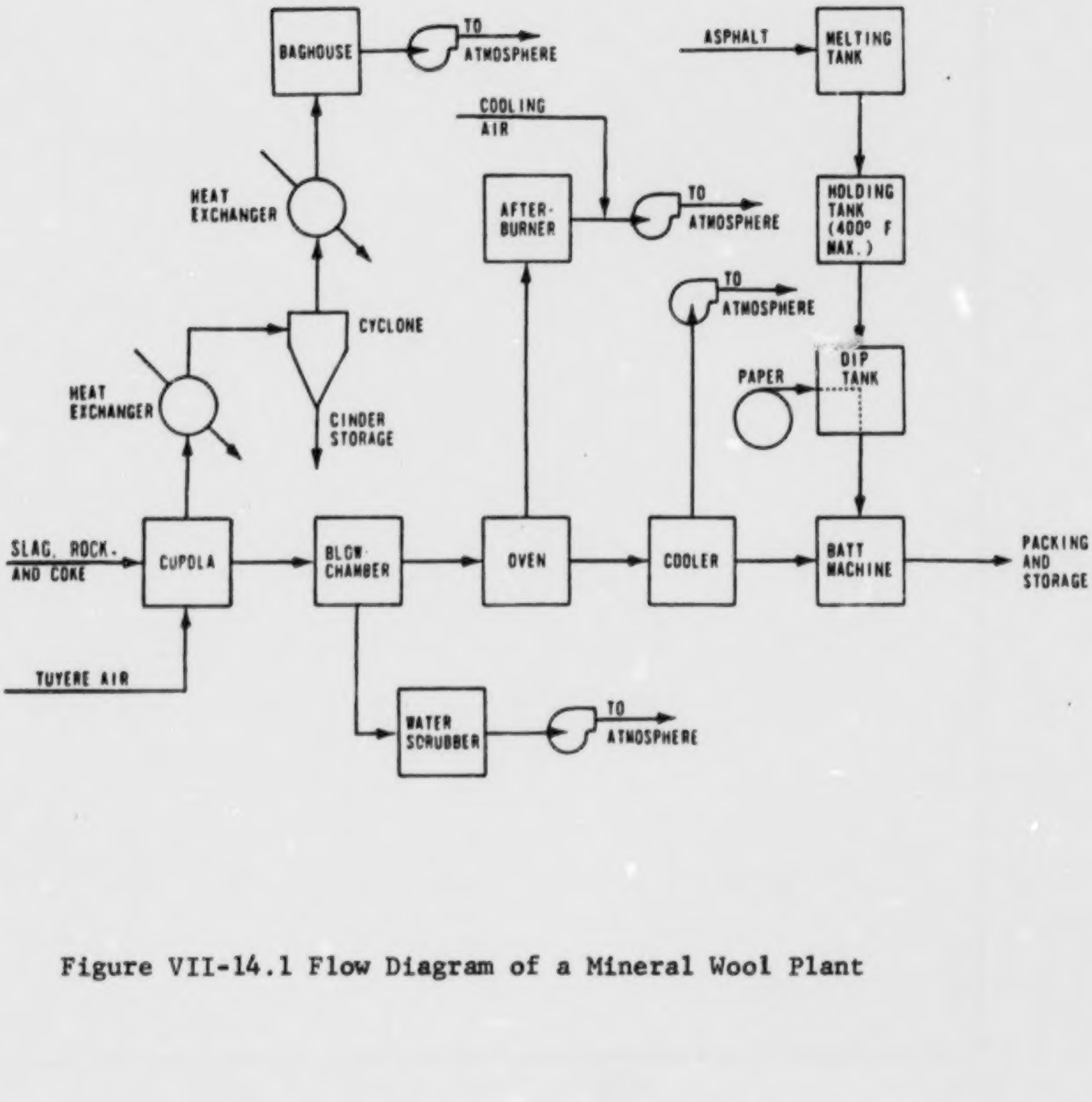

BAGHOUSE
TO ATMOSPHERE
ASPHALT
MELTING TANK
COOLING AIR
HEAT EXCHANGER
AFTER-BURNER
TO ATMOSPHERE
HOLDING TANK (400° F MAX.)
TO ATMOSPHERE
CYCLONE
DIP TANK
PAPER
HEAT EXCHANGER
CINDER STORAGE
SLAG, ROCK, AND COKE
CUPOLA
BLOW-CHAMBER
OVEN
COOLER
BATT MACHINE
PACKING AND STORAGE
TUYERE AIR
WATER SCRUBBER
TO ATMOSPHERE

Figure VII-14.1 Flow Diagram of a Mineral Wool Plant

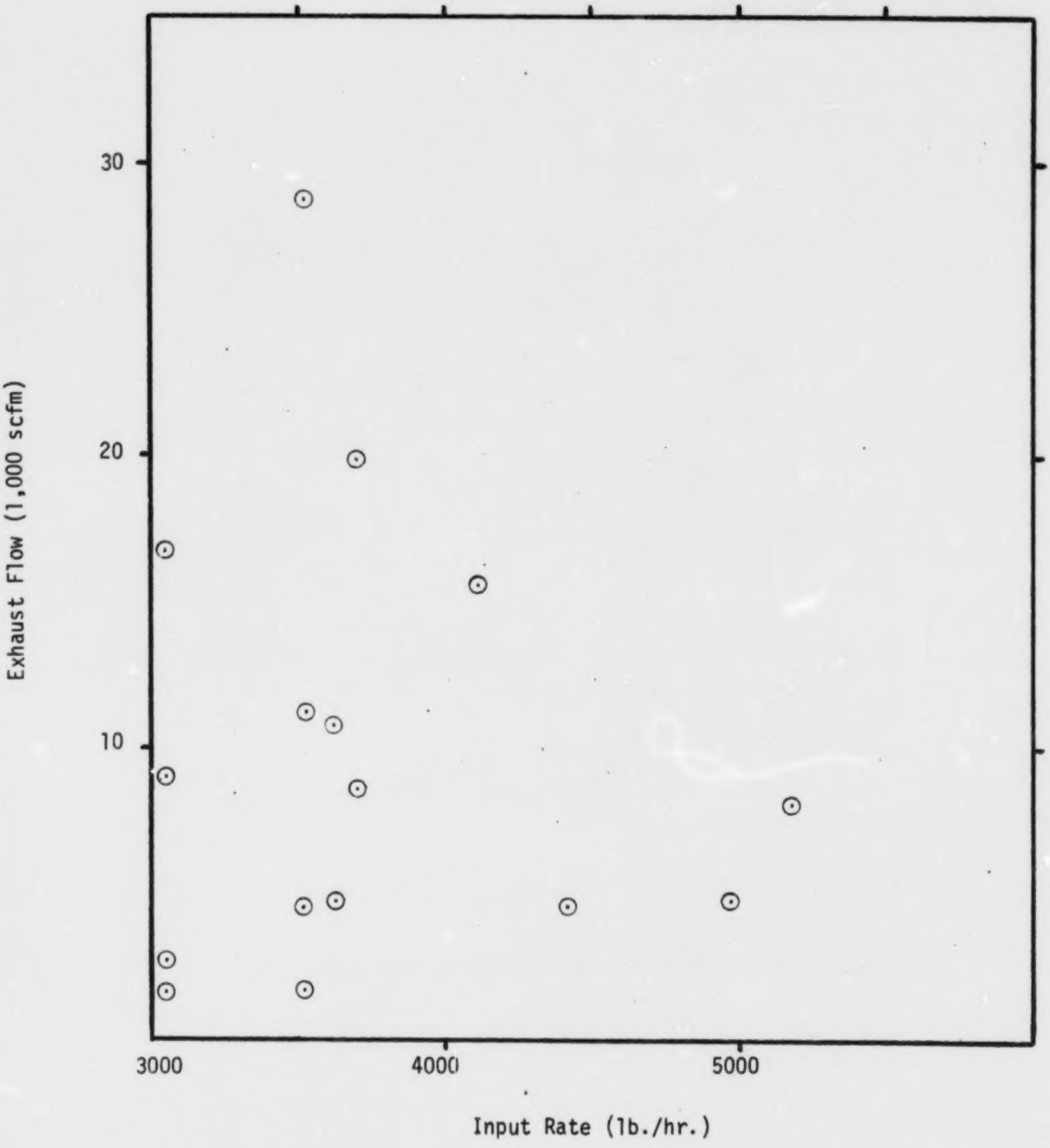


Figure VII-14.2 Exhaust flow vs. input rates from various mineral wool plants

CHAPTER VII-15

ROCK, GRAVEL AND SAND PLANT [C]

Rock, gravel and sand are all fundamental elements of the construction industry. The basic material associated with this category is hard rock. It is abundant nearly everywhere and plants are scattered throughout the U.S. catering to most all construction needs. Typical plant capacities average about 100 tph.

Dust is the only air pollution problem associated with rock, gravel and sand processing plants (Figure VII-15.1). Major emissions arise from the tertiory crushing and screening operations. Control equipment is generally a baghouse although cyclones, scrubber or water sprays have some application.

Stone crushing operations give rise to more dust problems than do sand and gravel operations. Most of the sand and gravel operations are wet processes taking place in a stream bed. Huge stones from quarries, after being crushed many times, provide all dry surfaces and large quantities of fines which are easily entrained by wind movement.

A ton of raw rock obviously will yeild a ton of crushed stone. The plants usually operate 5 or 6 days a week and 8 hours per day. Vagrant or fugitive dust may be very important during dry weather or when truck traffic is heavy or fast.

GAS FLOW RATE

Many rock, gravel and sand plants have no air pollution control devices to abate the dust caused by the crushing, screening and transporting operations. The dust becomes suspended in the air with little plume rise, but is carried vertically by ordinary convection currents. For this reason, those rock and gravel plants which have no air pollution control equipment should be treated as an area source instead of a point source. Thus, by knowing the particulate emission factor, lb./ton of rock, and the plant production rate in tons per hour, the time emission factor can be determined.

For those plants which do enclose processing operations to control dust, the flow rates will depend on the type system utilized. Almost every system is unique to the plant, some controlling all operations and some controlling only the crushing operation. Table VII-15.1 provides some guidance on the kind of system and exhaust flow from two installations. Exhaust flow ranged from 500 - 750 scfm per ton/hr. of aggregate produced.

GAS TEMPERATURE

Exhaust gas temperature for rock and gravel plants, for all practical purposes, is ambient conditions. Therefore, 60°F should be assumed unless specific data indicate otherwise.

GAS VELOCITY

Those plants having control equipment will have an exit velocity of near 30 fps. A low stack velocity, 5 fps, is suggested for use with dispersion equations.

STACK HEIGHT

Where no control equipment is utilized, except perhaps water sprays on the crushers, dust emissions will be generated at elevations ranging from ground level to about 50 feet maximum. Even if baghouses are used, stack height will not exceed 50 feet. Therefore, since most screens, crushers, and conveyors are elevated at least 20 to 40 feet, 30 feet is suggested for modeling purposes.

TABLE VII-15.1

Exhaust Gases From Rock Crushing Operations[15]

Plant size Input rate tons/hr.	Exhaust Flow 1000 scfm	Process	Control Equipment
40 - 45	23.7	Dolomite	Wet Scrubber
65	46.6	Dolomite	Wet Scrubber
100	5.1	Rock crushing	Crusher only

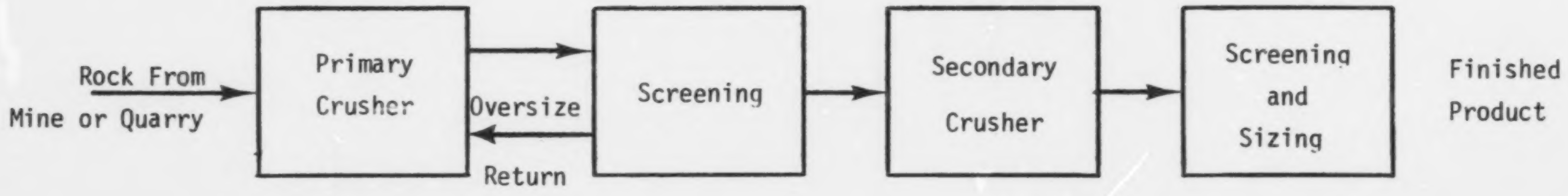

Rock From
Mine or Quarry
Primary
Crusher
Oversize
Return
Screening
Secondary
Crusher
Screening
and
Sizing
Finished
Product

Figure VII-15.1 Flow diagram for rock processing

CHAPTER VII-16

GLASS MANUFACTURING PLANT [E]

Soda-lime glass represents by far the largest tonnage of glass made today and serves for the manufacture of containers of all kinds, flat glass, auto glass, tumblers, and tableware. Soda-lime glass is produced on a mass scale in large direct fired continuous melting furnaces. Plant capacities range from a few pounds to several tons per day. The basic raw materials for soda glass include: silica sand, cullet, soda ash, limestone, niter, salt cake, arsenic, and a decolorizer. The raw materials are brought to the plant on railroad cars and unloaded into storage bins. The materials are withdrawn from the storage bins, batch weighed and blended in a mixer. The mixed batchs are fed continuously to the furnace and brought to a molten state 2,700°F. The glass is drawn from the furnace and then passed through a forming machine, which either presses, blows, rolls, draws or casts the molten glass to its final shape.[10]

The furnace is usually natural gas fired and is not a major source of air pollution. Grease and oils are used to lubricate the glass forming machine which is the source of significant smoking. Often the molten glass is sprayed after forming with annealing reagents to provide specific strength properties. The pollutant from this annealing process is usually of a Cl^- structure like HCl gas or $SnCl_4$. The annealing furnace is either electric heated or gas fired and presents no air pollution problem. Very few plants will have any control devices for any of the operations associated with the glass in the molten state. Some plants use cyclones and baghouses to handle the fine dusts eminating from the raw material transport operations. Glass manufacturing plants operate continuously, 24 hours per day.

Gas Flow Rates

The collection system for controlling dusts from the raw material transport operations is the only sizeable exhaust flow from the air polluting sources at the glass plants. The exact flow rate will depend on the size of the fans but flow rates are expected to be less than 10,000 scfm. No data were available for this specific source.[2]

The flow rate from the lubricating grease smoke (forming machine) and the annealing operations at one plant was 1200 scfm, driven by natural convection up a small stack.[16]

Gas Temperature

The exhaust gas temperatures from the air pollution sources sited above are mainly ambient. For calculation purposes, assume 100°F.

Gas Velocity

The exit velocity for these control units associated with the transport dust would be about 25 fps.

The exit velocity for the annealing and forming machines are due to natural comvection; assume 2 fps.

Stack Height

No data were available but stack heights will not be higher than the plant buildings. For calculation purposes, use 60 ft.

CHAPTER VII-17

FRIT MANUFACTURING[C]

Frit is a ceramic base product which is mainly used (when combined with a large portion of fluxes) as porcelain enamel coating for bathtubs, sinks, latrines, and household cooking pots. The preparation of frit is similar to the first steps of the manufacture of ordinary glass. The raw materials are mixed in proper proportions and charged to a melting furnace. Frit smelting is a batch operation and has varying melt times, however 3 hours is typical. The molten materials are then poured into a quenching tank of cold water, shattering the melt into friable pieces. The frit is further ground with a ball mill, mixed with a variety of fluxes and sprayed on as a surface coating of specific products.

The major source of air pollution in a frit manufacturing plant is the frit smelter. The principal air contaminants are dusts (metalic fumes and fluorides) and hydrogen fluoride gas. Most plants will control emissions from this source by using a baghouse or a high energy (venturi) scrubber.

Frit manufacturing plants operate continuously, 24 hours/per day and seven days a week.

Gas Flow Rate

Data were collected from several frit smelters and tabulated in Table VII-17.2. The flow rates were all less than 5000 scfm. Figure VII-17.1 is a plot of the data in Table VII-17.1.

Gas Temperature

The gas exit temperature for frit plants ranged from 340 to 960°F with a mean of about 600°F (Table VII-17.1). Several tests were made after the control device, however this data was not reported. The temperature is expected to drop about 100°F across a venturi scrubber and about 20°F across a baghouse.

Gas Velocity

The gas exit velocity was not available for the data in Table VII-17.1. The exit velocity is expected to be between 20 and 50 fps. Assume 40 fps for calculation purposes.

Stack Height

Baghouses do not usually have a stack, per se. Often a louvered wall acts as the emission point and is usually located at ground level. Venturi scrubbers will have a stack height of about 40 feet.

TABLE VII-17.1

Exhaust Gases from Frit Manufacturing[2]

Production Rate lb./hr.	Exhaust Flow scfm	Exhaust Temp. °F.
174	1390	450
174	1540	750
472	1630	900
472	1310	960
472	1400	950
292	1480	930
472	2240	630
472	2270	800
472	2260	840
174	1400	530
174	1600	840
162	1000	480
162	1000	480
857	2430	600
857	2430	600
890	4347	340
890	4347	340
1360	4280	570
1360	4280	552
1360	4280	564
1360	4280	570
1360	4280	552
1360	4280	564

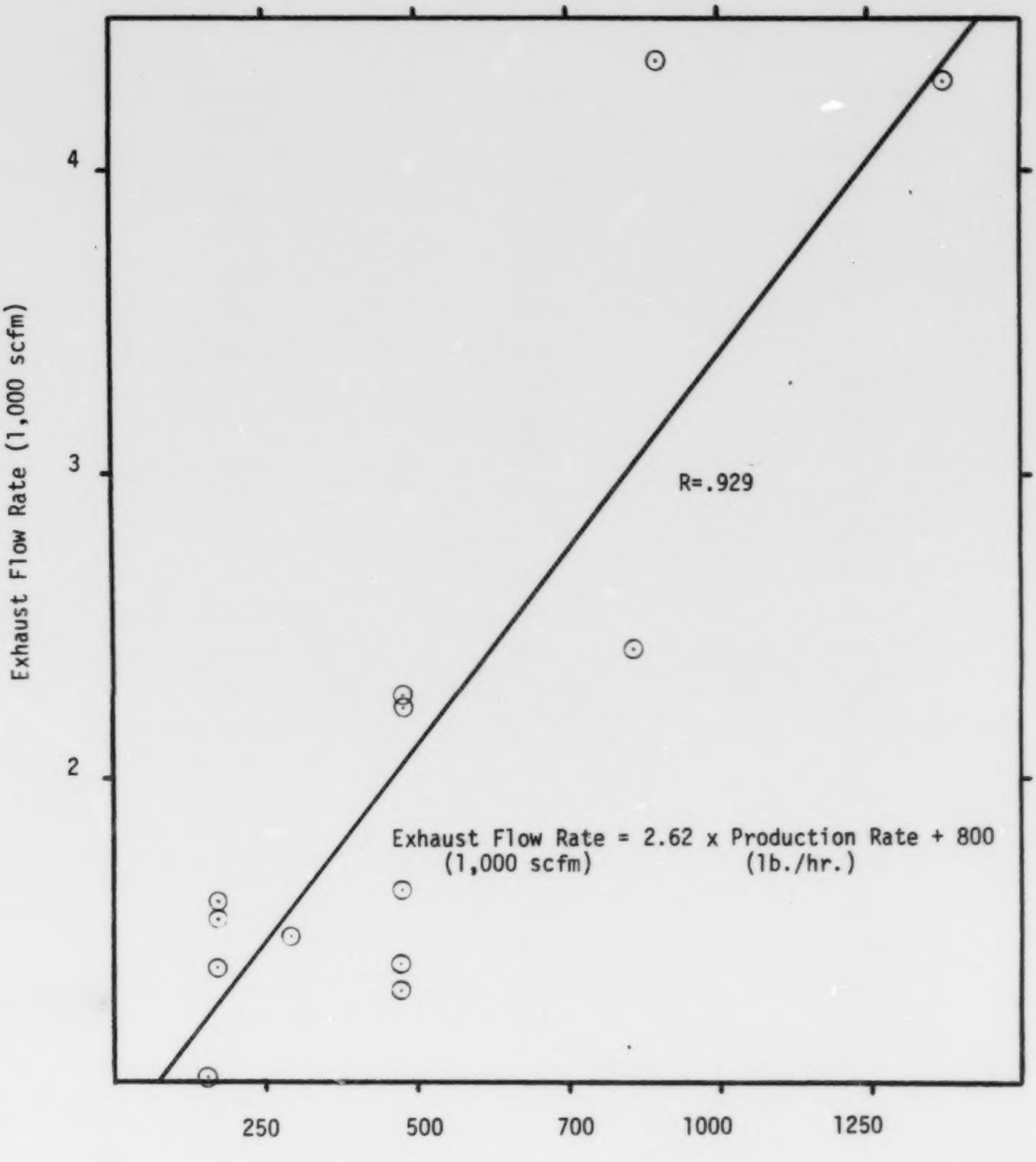


Figure VII-17.1 Exhaust flow rates for various frit production rates.

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CHAPTER VIII-1

PETROLEUM REFINERY [B]

In 1969 the total daily demand for petroleum products in the U.S. was 12 million barrels. Although the demand for petroleum products is growing at a rate of about 4 percent per year, the 263 operating U.S. petroleum refineries (Table VIII-1.1) are able to supply nearly all of the refined petroleum products needed to meet domestic requirements for transportation, heating, electric power generation and industrial uses. Each of these operations has its particular fuel need which is obtained by different methods of refining crude oil at a petroleum refinery. These plants are usually located near oil producing fields or harbors and serve as storage and distribution points for particular refining districts.

Refinery operations can be considered in terms of four major kinds of functions: separation, conversion, treating, and blending.[1] Crude oil is first separated into selected fractions by distillation. The relative volume of each fraction produced depends on the type of crude oil. Conversion of a specific distilled fraction to products of greater value is accomplished by cracking and reforming. The products from the separation and conversion steps are then treated, usually by the removal or inhibition of gum forming materials. As a final step, the refined base stocks are blended with each other and with additives to meet product specifications.

Separation

Crude oil is a mixture of many different hydrocarbons, some of them combined with small amounts of impurities. Crude oil usually consists of three families of hydrocarbons: paraffins (C_2H_{2n+2}), naphthenes (C_2H_{2n}), and aromatics (C_6H_6 in molecular structures). Significant elements other than carbon and hydrogen in the crude include sulfur, oxygen and nitrogen.

Primary separation is accomplised by distillation in crude topping units where the crude is heated and passed to fractionating towers for vaporization and separation (Figure VIII-1.1). Heavy fractions of the crude which do not vaporize in the topping operation will be separated by vacuum distillation.

The bottoms from the atmospheric tower go to the vacuum tower for further separation. Since cracking and coke formation occur at temperatures in excess of 800°F, this tower must be operated at a vacuum to recover, as overhead, materials boiling in excess of 800°F. The overhead from the crude is a fuel feed. The bottoms from these towers are high sulfur residual fuel oil.

Conversion

Conversion by cracking is employed to convert high molecular-weight hydrocarbons into products of lower molecular weights for gasoline production which is done with the use of catalytic cracking, reforming, isomerization, polymerization, and alkylation units.

Treating

As noted earlier, crude oils contain small amounts of impurities, one being sulfur, a major undesirable constituent. It is usually found in combination with hydrogen or hydrocarbons as hydrogen sulfide (H_2S), mercaptans (R-SH), sulfides (R-S-R), polysulfides ($R-S_x-R$) and thiophenes (ring compounds with sulfur as a member of the ring structure). During the refining process, part of the original sulfur compounds are often converted to H_2S and to lower molecular weight mercaptans. Sulfur removal from both product and intermediate feedstocks, therefore, will be necessary, since sulfur compounds are frequently odorous and may cause adverse plant and product quality effects. Removal processes which will be used include hydrogen treatment, chemical treatment, and physical treatment.

The sources of air pollutants from petroleum refineries are (Table VIII 1.2):

- heaters and boilers
- sulfur recovery units
- catalyst regeneration
- miscellaneous sources

The exhaust gas analysis for heaters and boilers would be the same as the combustion sources which have already been discussed. Likewise, factors for emission from sulfur recovery units are similar to the sulfuric acid plants and reference should be made to Chapter IV-13. Miscellaneous sources include purge lines or vents, leaks, pumps and compressors which have flow rates due to natural convection at ambient temperatures. Catalyst regeneration will be analyzed separately.

Cyclones, scrubbers or electrostatic precipitators are commonly installed on the high emission operations such as catalyst regeneration for air pollution abatement.[4] Improved housekeeping along with equipment maintenance is usually the least disruptive method of reducing emissions. Plants are operated on a continuous basis with shut-down only for periodic repair and maintenance.

GAS FLOW RATE

The major source of visible emissions from refineries is the catalyst regeneration units. The exhaust flow rates from these units are shown in Table VIII-1.3 and Figure VIII-1.2.[2] The exhaust flow rate can be determined accurately since the exhaust flow is 2,000 scfm for every 1,000 barrels per day throughput capacity.

GAS TEMPERATURE

Exhaust gas temperatures from catalyst regeneration units range from 485 to 850°F with a mean of 650°F.

GAS VELOCITY

No specific gas velocity data were obtained for exit velocities; however, 30 - 60 fps is typical.

STACK HEIGHT

Stack heights from several refiners ranged from 150 - 200 feet high on several petroleum catalyst regenerator unit stacks.

TABLE VIII-1.1

Capacities of U.S. Petroleum Refineries

State	No. Plants	Crude bpd
Alabama	6	34,620
Alaska	1	20,000
Arkansas	6	93,500
California	32	1,529,075
Colorado	4	42,900
Delaware	1	140,000
Florida	1	3,100
Georgia	2	9,500
Hawaii*	1	35,000
Illinois	11	704,100
Indiana	10	565,700
Kansas	12	389,300
Kentucky	3	128,500
Louisiana	16	1,190,850
Maryland	2	19,400
Michigan	8	146,050
Minnesota	3	138,300
Mississippi	4	168,700
Missouri	1	83,000
Montana	9	128,200
Nebraska	1	4,000
New Jersey	6	523,500
New Mexico	6	42,610
New York	2	76,900
North Dakota	2	55,000
Ohio	11	491,600
Oklahoma	14	449,367
Oregon	1	11,000
Pennsylvania	13	628,920
Rhode Island	1	7,500
Tennessee	1	28,500
Texas	47	3,118,250
Utah	5	11,950
Virginia	1	43,600
Washington	6	219,000
West Virginia	2	8,570
Wisconsin	2	29,500
Wyoming	9	132,900
Total	263	11,522,512

TABLE VIII-1.2

Potential Sources of Specific Emissions From Oil Refineries

Emission	Potential sources
Oxides of sulfur	Boiler, process heaters, catalytic cracking unit regenerators, treating units, H_2S flares, decoking operations.
Hydrocarbons	Loading facilities, turnarounds, sampling, storage tanks, waste water separators, blow-down systems, catalyst regenerators, pumps, valves, blind changing, cooling towers, vacuum jets, barometric condensers, air-blowing, high pressure equipment handling volatile hydrocarbons, process heaters, boilers, compressor engines.
Oxides of nitrogen	Process heaters, boilers, compressor engines, catalyst regenerators, flares.
Particulate matter	Catalyst regenerators, boilers, process heaters, decoking operations, incinerators.
Aldehydes	Catalyst regenerators.
Ammonia	Catalyst regenerators.
Odors	Treating units (air-blowing, steam-blowing), drains, tank vents, barometric condenser sumps, waste water separators.
Carbon monoxide	Catalyst regeneration, decoking, compressor engines, incinerators.

TABLE VIII-1.3

Exhaust Gases from Catalyst Regeneration Units in Petroleum Refineries [2]

Operation	Input Rate bpd	Exhaust Flow 1000 scfm	Exhaust Temp. °F
Catalyst Regeneration Units	50.00	112.00	820
	31.54	28.00	510
	24.00	22.20	520
	46.26	97.50	485
	11.02	27.00	840
	15.92	27.00	700
	34.00	64.00	530
	10.00	22.00	660
	11.00	27.60	610
	12.60	24.00	850
	12.10	25.00	740
	13.10	27.00	810
	12.06	23.00	710
	7.06	13.30	610
	11.00	16.80	680
	31.80	80.60	
	11.90	14.90	

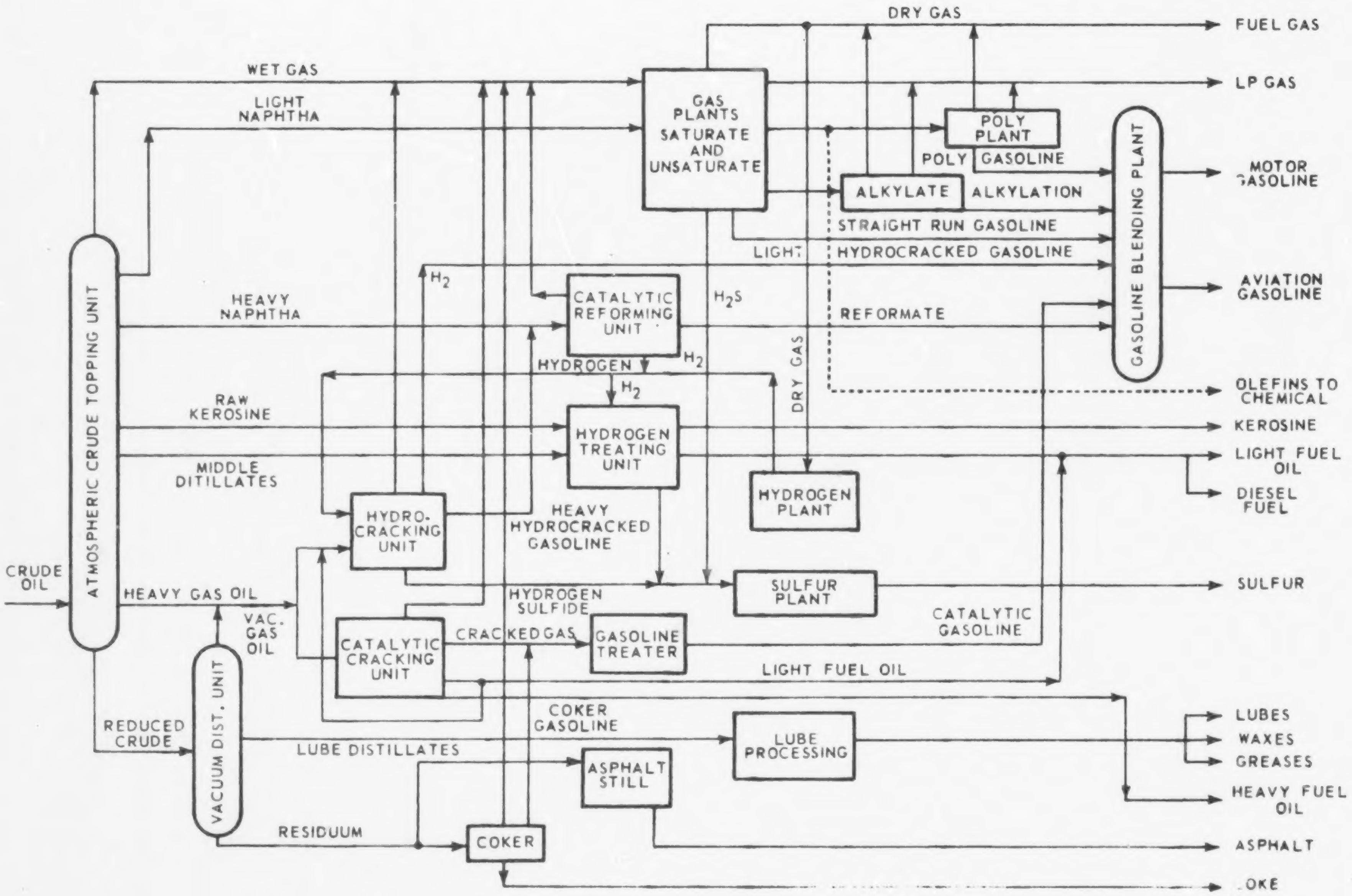
CRUDE OIL
ATMOSPHERIC CRUDE TOPPING UNIT
WET GAS
LIGHT NAPHTHA
HEAVY NAPHTHA
RAW KEROSINE
MIDDLE DISTILLATES
HEAVY GAS OIL
VAC. GAS OIL
REDUCED CRUDE
VACUUM DIST. UNIT
LUBE DISTILLATES
RESIDUUM
GAS PLANTS SATURATE AND UNSATURATE
DRY GAS
POLY PLANT
POLY GASOLINE
ALKYLATE
ALKYLATION
STRAIGHT RUN GASOLINE
LIGHT HYDROCRACKED GASOLINE
H_2
H_2S
CATALYTIC REFORMING UNIT
REFORMATE
HYDROGEN
H_2
H_2
DRY GAS
HYDROGEN TREATING UNIT
HYDROGEN PLANT
HYDRO-CRACKING UNIT
HEAVY HYDROCRACKED GASOLINE
HYDROGEN SULFIDE
SULFUR PLANT
CATALYTIC CRACKING UNIT
CRACKED GAS
GASOLINE TREATER
CATALYTIC GASOLINE
LIGHT FUEL OIL
COKER GASOLINE
LUBE PROCESSING
ASPHALT STILL
COKER
GASOLINE BLENDING PLANT
FUEL GAS
LP GAS
MOTOR GASOLINE
AVIATION GASOLINE
OLEFINS TO CHEMICAL
KEROSINE
LIGHT FUEL OIL
DIESEL FUEL
SULFUR
LUBES
WAXES
GREASES
HEAVY FUEL OIL
ASPHALT
COKE

Figure VIII-1.1 Processing plan for a typical complete refinery

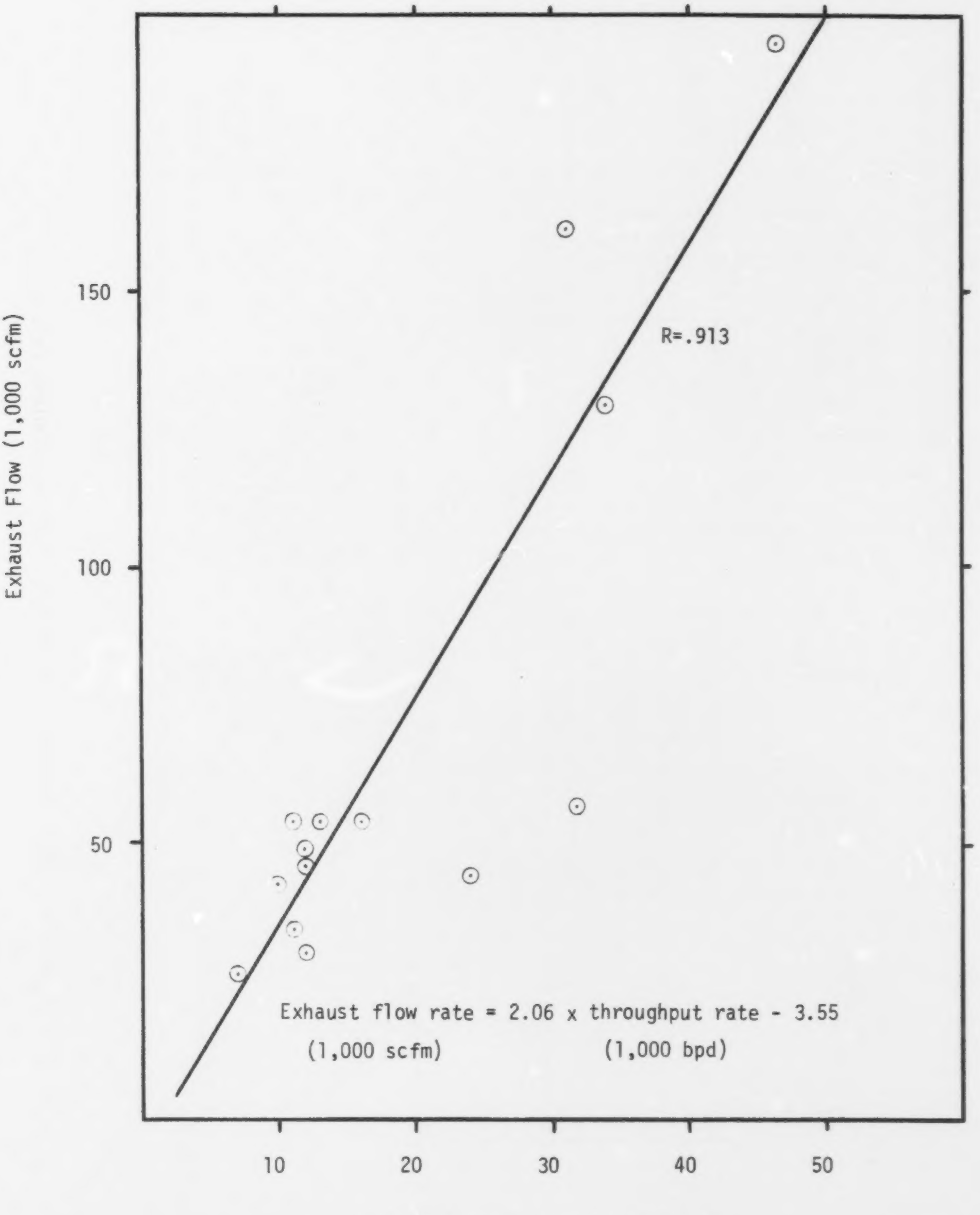

Figure VIII-1.2 Exhaust flow rates from catalyst regeneration units

CHAPTER VIII REFERENCES

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2. "Air Pollution Engineering Manual", U.S. Dept. of Health, Education, and Welfare, Public Health Service, Publication No. 999-AP-40, 1967.

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CHAPTER IX-1

KRAFT PULP MILL[B]

As of December 31, 1968 there were 116 kraft pulp mills in the United States with a pulp capacity of over 30 million tons. Actual production in 1968 totalled 24 million tons. The mills are located principally on the east and west coasts with the greatest concentration in the southeastern United States. The kraft process accounts for over 75 percent of all the chemical pulp produced in the U.S. but only 50 percent of the total mills. In other words the kraft mills tend to be larger than sulfite or neutral sulfite semi-chemical (NSSC) mills. Together these three processes account for 95 percent of the total wood pulp produced in the U.S.

An excellent description of the process has been prepared in an earlier study and is quoted here without change.[1]

Pulp wood can be considered to have two basic components, cellulose and lignin. The fibers of cellulose, from which the pulp is made, are bound together in the wood owing to the presence of the lignin. To render cellulose usable for pulp manufacture, any chemical pulping process must first remove the lignin.

The major discriminating factor of the kraft process (Figure IX-1.1) lies in its utilization of a solution of sodium sulfide and sodium hydroxide in water to dissolve lignin from wood. This liquor is mixed with wood chips in a large, upright pressure vessel, known as a digester, and cooked for about 3 hours with steam at a gauge pressure of approximately 110 pounds per square inch. Figure IX-1.2 shows feed rate versus production rate.

During the cooking period the digester is relieved periodically to reduce the pressure build-up of various gases within.

When cooking is completed, the bottom of the digester is suddenly opened, and its contents forced into the blow tank. Here the major portion of the spent cooking liquor containing the dissolved lignin is drained and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter, which removes the chunks of wood not broken down during cooking. It then proceeds through various intermittent stages of washing and bleaching, after which,it is pressed and dried into the finished product.

A major reason for the economic success of this type of pulping operation lies in its ability to recover most of the chemicals from the spent cooking liquor for re-use in subsequent cooks. The recovery process is initiated by introducing the spent ("black") liquor from the blow tank into a multiple effect evaporator where it is concentrated into a mixture with a density of about 25° Baume. The spent or black liquor is further concentrated in a direct contact evaporator, which, by bringing the liquor into direct contact with recovery furnace flue gases, evaporates an additional portion of water.

The combustible, concentrated black liquor thus produced is then forced through spray nozzles into the recovery furnace, where it is burned to recover a portion of the heat by oxidation of the dissolved lignin and to conserve the inorganic chemicals, which fall to the floor of the furnace in a molten state.

The resulting melt, which consists mainly of a mixture of sodium sulfide and sodium carbonate, is withdrawn from the furnace and dissolved with water and weak liquor from the causticizing plant. The "green" liquor thus produced is pumped into a causticizer, where the sodium carbonate is converted to sodium hydroxide by the addition of calcium hydroxide. The calcium carbonate resulting from the reaction precipitates from the solution and is collected and introduced into a lime kiln, where it is converted to calcium oxide. This is slaked to produce calcium hydroxide for further use in the causticizer.

The effluent solution produced by the causticizing reaction with the green liquor contains sodium hydroxide, sodium sulfide, and smaller quantities of sodium sulfate and sodium carbonate. Known as "white" liquor, this solution is withdrawn and re-used in the digestion process.

The sources of particulate and sulfurous gas emissions from a kraft pulp mill in order of importance are: 1.) recovery furnace, 2.) lime kiln, 3.) power plant, 4.) digester relief and blow tank, 5.) black liquor oxidation tower, 6.) dissolver tank and 7.) evaporator.

Controls are generally precipitators on the recovery furnace, scrubbers on the lime kilns, mechanical collectors on the back fed boilers, and combustion in the lime kiln of many of the odorous gas streams.

Kraft mills operate continuously about 350 days per year with down time only for routine maintenance.

Exhaust gases from the bark-fired power plants were discussed in Chapter II-7 and will not be repeated here. Other processes are examined in detail.

"Recovery Furnace"

GAS FLOW RATE

Data from 20 separate recovery furnaces were tabulated and plotted to show the pulp production rate versus exhaust gas flow rate (Table IX-1.1 and Figure IX-1.3). The production of 1 ton of air dried pulp was assumed to be directly related to the amount of black liquor solids (2700 lb.) fed to the recovery furnace. A systems study showed 272,000 scf of exhaust gases would be discharged from the recovery furnace for every ton of air dried pulp produced.[4] Stated another way, the flow rate is 189 scfm for every ton/day of pulp produced.

GAS TEMPERATURE

The systems study showed 325°F to be an average temperature for the exhaust gases from the precipitator. The range was from 325 to 375°F. When scrubbers were used the exit temperature ranged from 165 to 200°F.

GAS VELOCITY

Gas velocity from 6 black liquor recovery furnace stacks ranged from 13 to 38 fps. Assume 30 fps when no data are available.

STACK HEIGHT

Stack height was available for [illegible] recovery furnaces; the range was from 125 to 400 feet with 250 feet being rather typical.

"Lime Kiln"

Calcining of the calcium carbonate sludge from the causticizing reaction is performed in the lime kiln. Dust loading varies with kiln length, soda content, and gas velocity. With a short kiln (100 feet), high velocity, and low soda content, dust loading will be high. With a long kiln (300 feet) and high soda content, dust loading will be low.[6]

GAS FLOW RATE

The systems study showed a gas flow rate from the lime kilns of 38,199 scf per ton of pulp produced.[4] Another investigator used 37,265 scf per ton.[5] One plant showed 18,700 scfm from the lime kiln on a 500 ton/day mill. The 38,100 converts to 13,250 scfm for a 500 ton/day mill (Table IX-1.2). Therefore assume 26 scfm of lime kiln exhaust gas per ton/day of pulp production.

GAS TEMPERATURE

The systems study assumed an average exit temperature of 180°F. One other data point showed 150°F so the 180°F should be used.

GAS VELOCITY

No data were available on stack gas velocity. Assume 20 fps when no data exist.

STACK HEIGHT

Data for 6 mills showed steel stubs to be used on the lime kiln exhaust. In the absence of other data assume 30 feet for stack height.

"Digester Relief and Blow Tank"

Sulfur compounds are released during the cooking and discharge of pulp to the blow tank. A large quantity of steam is released, but it is normally condensed.

GAS FLOW RATE

Non-condensible gases from the digester or blow tank discharge at 155 scfm at one 500 ton/day mill.[2] Another author reported 137 and 274 scf per ton of pulp produced by continuous and batch type digesters.[5] Thus, for a 500 ton/day mill 48 scfm or 100 scfm would be generated. The systems study reported 274 scf per ton when an accumulator was used.

GAS TEMPERATURE

The system study reported 120°F for these exhaust gases. No other data were found.

GAS VELOCITY

No data were available; assume 20 fps.

STACK HEIGHT

No data were available; assume 30 feet.

"Dissolving Tank"

GAS FLOW RATE

The system study reported an average 36,100 scf per ton of pulp produced.[4] Hough reports 24,000 scf per ton of pulp produced.[5] Walther reported 20,700 scfm from the dissolver tank vent on a 500 ton/day mill; this is equivalent to 59,600 scf per ton of pulp. Therefore, use 36,100 scf per ton of pulp produced or 40 scfm per ton/day.

GAS TEMPERATURE

Exhaust temperature for uncontrolled tanks or those using mesh pads will be about 200°F. If a scrubber is used 160°F will be the exit temperature.

GAS VELOCITY

No data were available, but 20 fps may be assumed.

STACK HEIGHT

No data were available, but 30 feet may be assumed.

"Miscellaneous Other Operations"

Remaining pollution sources in a kraft mill which may generate some air contaminants and their total volume per ton of pulp produced are tabulated below.[4,5]

Department	Total Volume (scf/ton)
Washers	70,000
Bleach Plant	80,000
Evaporators	300
Power Boiler (Hag Fuel)	300,000
Paper Machine	430,000
Slaker	7,000

TABLE IX-1.1

Exhaust Gases From Recovery Furnaces of Kraft Pulp Mills [1,2,3,4]

Production Rate tons/day of pulp	Input Rate 1000 lb./day Black Liquor Solids	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameters ft.
165[1]	1,200		180			
150[1]		50	300			
260[1]		58	165			
500[2]		167				
Recovery Furnace[3]						
680	1,900	220			250	14.5
680	1,900	220			a	a
358	1,000	116			250	12
464	1,300	150			a	a
893	2,500	290			a	a
314	880	102		38	200	8
428	1,200	140		23	225	12
537	1,500	175			a	a
1,000	2,800	325			250	16
518	1,450	170			350	9.5
894	2,500	290			a	a
894	2,500	290		27	400	15.5
340	950	110		29	210	9
500	1,400	160				a
197	550	60		13	125	10
197	550	60		13	150	10
537	1,500	175			-	-

Calculated from black liquor feed rate assuming 2,700 lb. black liquor/ton of pulp produced.

TABLE IX-1.1

Exhaust Gases from Recovery Furnaces of Kraft Pulp Mills [1,2,3,4] (cont'd)

Production Rate tons/day of pulp	Input Rate 1000 lb./day Black Liquor solids	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Exit Velocity fps	Stack Height ft.	Stack Diameters ft.
Recovery Furnace[4]						
Sample #-tpd						
1-1		218	325			
2-1		318.6	325			
3-1		263.5	325			
4-1		276.7	325			
5-1		254.4	325			
6-1		314.5	325			
7-1		236.6	200			
8-1		311.8	325			
9-1		-	-			
10-1		253.9	375			
Average		272				
1[5]		330				

Exhaust Gases From Lime Kilns of Kraft Pulp Mills [1,2,3,4]

Production Rate	Input Rate	Exhaust Flow 1000 scf/bbl	Exhaust Temp. °F	Reference
Sample # - tpd				
1 - 1		32	180	Hendrickson
2 - 1		-	-	
3 - 1		42	180	
4 - 1		46	180	
5 - 1		42	180	
6 - 1		54	180	
7 - 1		57	180	
8 - 1		47	180	
9 - 1		57	180	
10 - 1		40	180	
Ave.		46		
		45		Hough
tons/day		1000 scfm		
500		18.7		Walthers
	250 tons calcine/day	26	150	Kenline

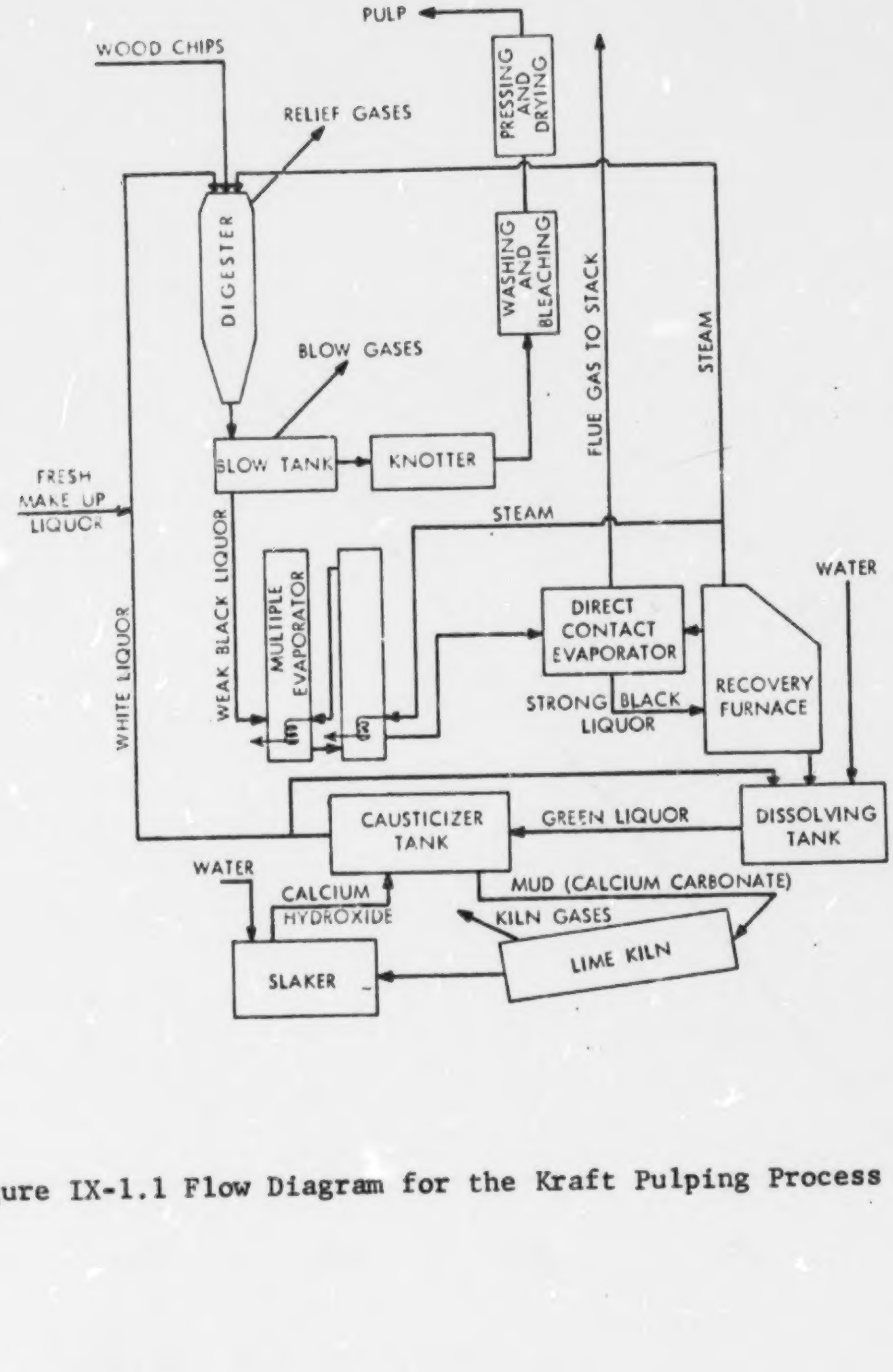
PULP
WOOD CHIPS
PRESSING AND DRYING
RELIEF GASES
DIGESTER
WASHING AND BLEACHING
FLUE GAS TO STACK
STEAM
BLOW GASES
BLOW TANK
KNOTTER
FRESH MAKE UP LIQUOR
STEAM
WEAK BLACK LIQUOR
MULTIPLE EVAPORATOR
WHITE LIQUOR
DIRECT CONTACT EVAPORATOR
WATER
RECOVERY FURNACE
STRONG BLACK LIQUOR
CAUSTICIZER TANK
GREEN LIQUOR
DISSOLVING TANK
WATER
CALCIUM HYDROXIDE
MUD (CALCIUM CARBONATE)
KILN GASES
LIME KILN
SLAKER

Figure IX-1.1 Flow Diagram for the Kraft Pulping Process

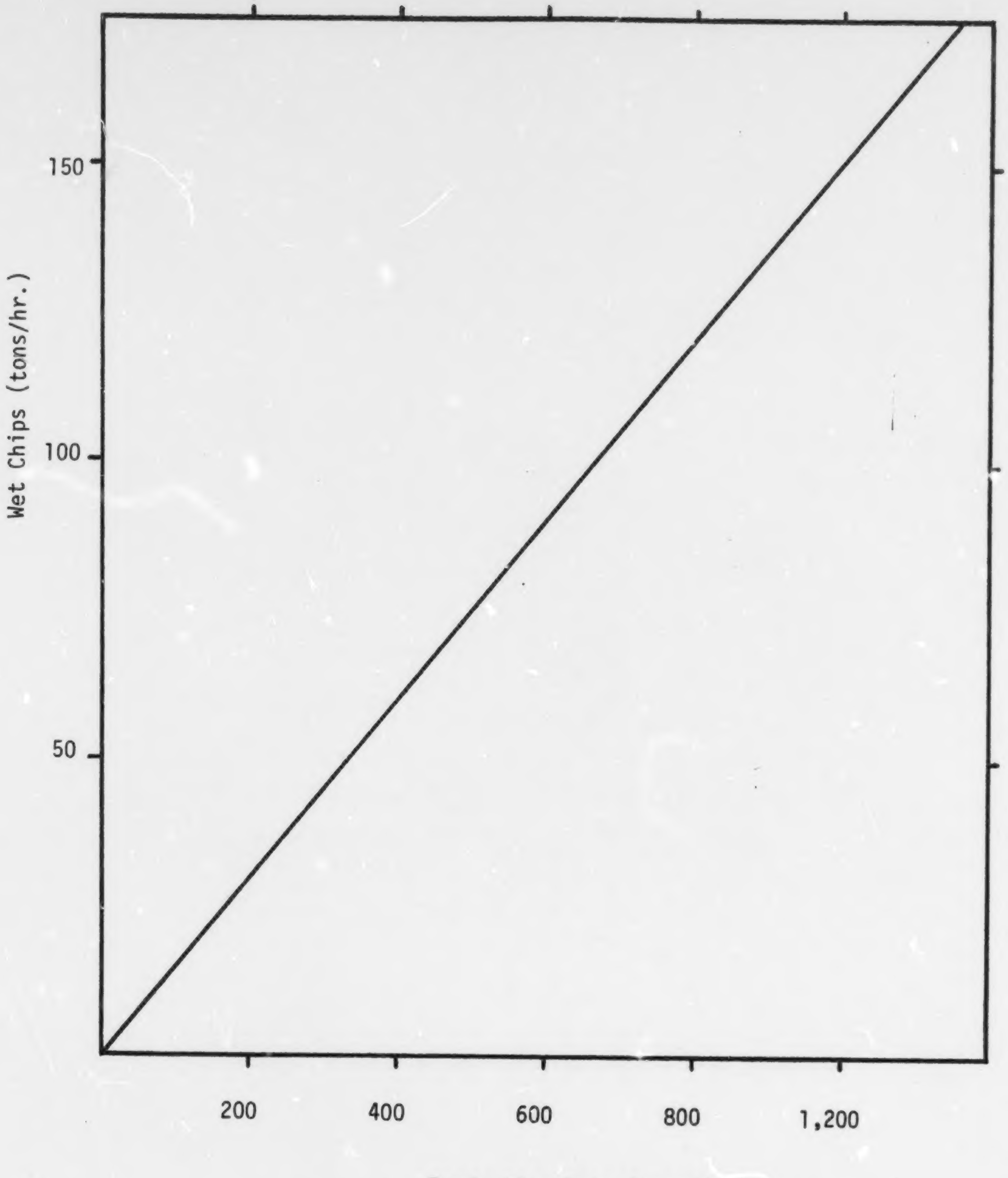

Figure IX-1.2 Feed rate vs. Production rate for kraft pulp mills

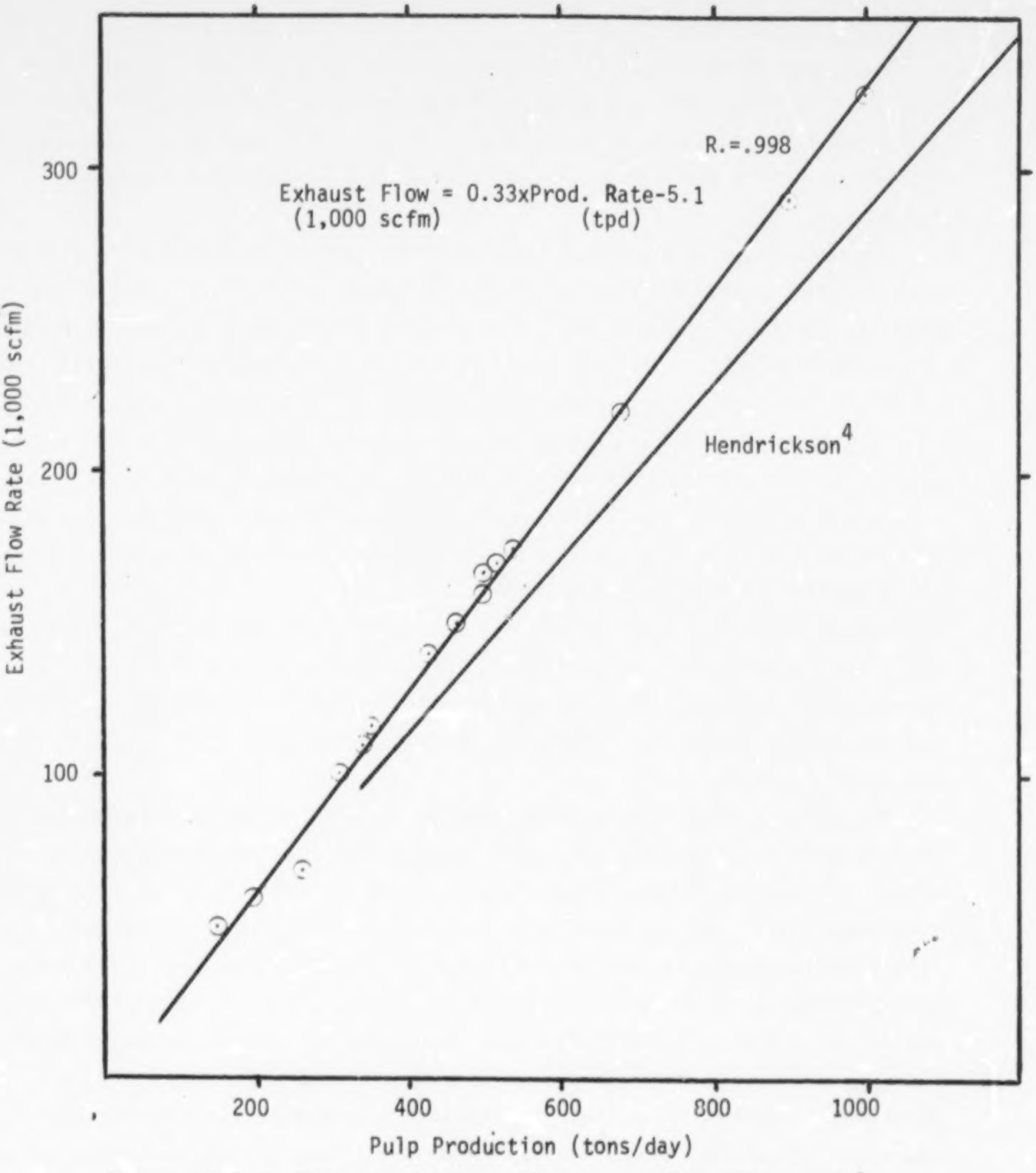

Figure IX-1.3 Recovery furnace exhaust gas flow rate vs. pulp production rate.

CHAPTER IX-2

SULFITE PULP MILLS [C]

There are 43 sulfite pulp mills in the U.S. with an annual capacity of about 3.5 million tons. The average size of these mills is 10,875 tons of air dried pulp per day. Fifty percent of the sulfite pulp production comes from the northwestern United States. The plants operate continuously 350 days per year.

The sulfite pulping process dominated the commercial pulping field from 1890 to 1930 but has declined in importance because of chemical costs and disposal problems. A description of the process is quoted from the systems study.[4]

Sulfite pulping is an acid chemical method of dissolving the lignin that bonds the cellulose fibers together. Many of the older mills use a sulfurous acid - calcium bisulfite solution for the cooking acid. Calcium-base spent liquor, because of problems associated with evaporation and chemical recovery, is discarded and may result in water pollution problems. In order to overcome this problem several other acid bases have been developed, the most important being sodium, magnesium, and ammonium.

Because sulfite pulp is used in a wide variety of end products, operations will vary considerably among mills. These products can include pulp for making high grade book and bond papers and tissues, for combining with other pulps, and for making dissolving pulp for producing cellophane, rayon, acetate, films, and other products.

The pulping operation involves cooking the wood chips in the presence of an acid within a digester. The heat required for cooking is produced by the direct addition of steam to the digester or by the steam heating of the recirculated acid in an external heat exchanger. The cooking liquor, or acid, is made up of sulfurous acid and a bisulfite of one of the four above bases. The sulfurous acid is usually produced by burning sulfur or pyrites and absorbing the SO_2 in liquor. Normally, part of the sulfurous acid is converted to the base bisulfite to buffer the cooking action. During the cooking action it is occasionally necessary to vent the digester as pressure rises within the digester. These vent gases contain large quantities of sulfur dioxide and, therefore, are recovered for reuse in the cooking acid.

Upon completion of the cooking cycle the contents of the digester, consisting of cooked chips and spent liquor, are dishcarged into a tank.

During this operation some water vapor and fumes escape to the atmosphere from the tank vent. The pulp then goes through a washing stage, where the spent liquor is separated from the fibers. The washed pulp is either shipped or kept within the plant for further processing.

The spent liquor that was washed out of the pulp can be discarded or, as an alternative, can be concentrated by evaporation and run through a recovery cycle. The concentrated liquor is sprayed into a furnace where the organic compounds are burned. The residual inorganic compounds may be collected and reused in the manufacture of cooking acid.

Emissions consist of sulfur oxides and particulates. Controls generally involve use of cyclones and scrubbers on the recovery boiler and mechanical collectors on the boiler.

Major emission sources are the power plant (discussed earlier), recovery furnace, digester and dump tank, and miscellaneous sources such as evaporators, washers and screens, and the bleach plant.

"Recovery Furnace"

GAS FLOW RATE

Exhaust gas volume from the recovery furnace is reported to be 297,000 - 339,200 scf per ton of air dry pulp produced.[4] Not many of the sulfite pulp mills will recover chemicals, so this point should be checked before estimating emissions.

GAS TEMPERATURE

Exhaust gas temperature was reported to average 165°F.

GAS VELOCITY

No data were available, but assume 20 fps.

STACK HEIGHT

No data were available, but assume 200 feet since a fairly tall stack is expected.

"Digester Relief and Dump Tank"

GAS FLOW RATE

Exhaust gas flow rates are small, about 414 scf per ton of pulp produced. In some sulfite mills without chemical recovery the digester relief gases are reported to be 16,600 scf per ton.[4]

GAS TEMPERATURE

Gas temperature of these gases ranges from 60 to 250°F. When data are not available, assume 180°F.

GAS VELOCITY

No data were available, but assume 20 fps.

STACK HEIGHT

No data were available, but assume 30 feet.

"Miscellaneous Sources"

From the comprehensive study of control of atmospheric emissions in the wood pulping industry the following gas flow and temperature data are offered for miscellaneous sources.

Source	Total Flow scf/ton	Temperature °F
Evaporator	44	140
Washer and screens	86,100	125
Bleach plant	37,600	90
Acid tower	15,000	70
Boiler	240,100	350

CHAPTER IX-3

NSSC PULP MILLS[c]

The neutral sulfite semichemical (NSSC) pulping process is used mainly for making corrugated board. There are 43 mills in the U.S. producing some 3.5 million tons annually. The average production rate is 10,675 tons/day of air dry pulp.

A description of the NSSC process is quoted as it appears in the systems study of the pulping industry.[4]

The process derives its name "neutral sulfite" from the fact that the solution containing the cooking chemicals, consisting of sodium sulfite and sodium carbonate, is maintained above a pH of 7.0. The name "semichemical" is given because all of the cementing material is not completely removed by the chemical reaction and some mechanical disintegration is required to separate the fibers. Because some of the cementing material remains with the fibers it follows that the "yield" for this process is higher than that for a conventional full-chemical pulping process. Semichemical pulping may produce yields of 60 to 80 percent.

The cooking process is carried out in either batch or continuous digesters. Steam maintains the temperature and pressure of the cook within certain limits depending on the end use of the pulp. During this cooking stage odorous gases are created within the digester. At the completion of the cooking cycle, residual pressure within the digester is used to discharge the entire contents of the batch digester into a blow tank. Waste gases, containing the odorous compounds formed in the digester, are usually vented to the atmosphere.

Before the pulp fibers can be used in the production of paper products the spent liquor must be washed from the pulp. This washing is usually performed on multi-stage drum filters. If a kraft system is adjoining, the NSSC spent liquor can be mixed with the spent kraft liquor, up to a limiting percentage, and burned in the recovery furnace. The recovered chemicals are used entirely in the kraft system. Emissions of both sulfur dioxide and hydrogen sulfide may be increased from the kraft recovery furnace when NSSC liquor is added.

Besides the two above spent liquor systems, one discharging the spent liquor to sewer and other mixing NSSC liquor with kraft liquor, there is a fluidized bed recovery system. This is a patented system in which the NSSC spent liquor is oxidized in a reactor producing a pelleted product, consisting of sodium carbonate and sodium sulfate.

The one source of emissions common to all NSSC pulp mills is the blow tank. About half (15-20) of the mills have no chemical recovery. Ten or 15 deliver spent liquor to an adjoining kraft recovery system and 2 to 4 recover chemicals in a fludizied bed process.

"Blow Tank"

GAS FLOW RATE

Exhaust gases total 17,350 - 27,600 scf/ton from the blow tank. As an average assume 23,700 scf/ton.

GAS TEMPERATURE

From all three types of NSSC pulp mills the blow tank exhaust temperature runs 200 - 212°F. Since the more popular processes discharge blow gases at 212°F use this for calculations.

GAS VELOCITY

No data were available; assume 20 fps.

STACK HEIGHT

No data were available; assume 30 feet.

"Absorption Tower"

GAS FLOW RATE

For those NSSC mills which use an absorption tower and sulfur burner emissions can be expected to total 3,400 scf/ton.

GAS TEMPERATURE

Exhaust gas temperatures from the absorption tower exit at 100°F.

GAS VELOCITY

No data were available; assume 20 fps.

STACK HEIGHT

No data were available; assume 30 feet.

"Recovery Furnace"

GAS FLOW RATE

Where spent liquor is sent to a kraft mill for chemical recovery, the emissions from the NSSC portion are 22,500 scf/ton.

GAS TEMPERATURE

Exit gas temperatures after a precipitator can be expected to be 325°F.

GAS VELOCITY

No data were available; assume 20 fps.

STACK HEIGHT

No data were available, but recovery furnace stacks are expected to be 200 feet.

"Fluidized Bed Reactor"

GAS FLOW RATE

After the exhaust gases have passed through a venturi scrubber, the volumetric flow will be 121,700 scf/ton.

GAS TEMPERATURE

Average temperature following the venturi will be 180°F.

GAS VELOCITY

No data were available; assume 20 fps.

STACK HEIGHT

No data were available; assume 30 fps.

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CHAPTER X-1

DRY CLEANING PLANT [C]

Some 50,000 or so dry cleaning plants are located throughout the U. S. In San Francisco, which may be typical of the larger cities, 720 plants were operating in 1965.[1] Two types of solvents are commonly used by the dry cleaning industry: petroleum solvents (e.g. Stoddard solvent and 140°F solvent) and chlorinated solvents (e.g. perchloroethylene). A typical dry cleaning plant will have a capacity on the order of 500 pounds/day. Plants usually operate 8 hr./day and 5 or 6 days a week. The amount of solvent necessary to clean clothes varies with the type solvent. For perchloroethylene it takes 4.9 lbs. solvent per pound of clothes; for the Stoddard solvent it takes 7.6 lbs. solvent per pound of clothes;and for Safety 140°F the ratio is 6.5 lbs. solvent per pound of clothes cleaned.[1]

The basic air pollution problem associated with dry cleaning is solvent evaporation. Clothing or other textiles are cleaned by agitation in a solvent bath, and then, after being rinsed in a clean solvent, are placed in a drier to evaporate the latent solvent. The principal control device for the chlorinated solvents is a water cooled condensor which is an integral part of the closed cycle in a tumbler or drying system. About 95 percent of the solvent is recovered here for reuse. Activated carbon adsorbers may also be used in addition to the water cooled condenser to provide an overall solvent recovery efficiency of 97 - 98 percent.[2] Other plants do not attempt to recover the solvents. Instead they use catalytic afterburners to incinerate exhaust waste gases. There are no commercially available control units for solvent recovery in petroleum based plants (Stoddard and 140°F solvents), because it is not economical to recover the vapors. Stoddard and 140°F solvents cost $.20/gal. Perchloroethylene costs $2.00/gal.

GAS FLOW RATE

The exhaust gas flow rates from dry cleaning units (driers) are relatively low, less than 10,000 scfm for most size plants. Natural gas is commonly used as the heat source. Driers usually have name plates denoting size and other related operating data. Table X-1.1 lists operating data.[3]

GAS TEMPERATURE

Temperatures in driers do not exceed about 150°F; hotter temperatures would damage the clothing. Gas temperatures for three units without incinerators ranged from 75 to 110°F. Gas exit temperatures with incinerators would be about 1000°F. For modeling assume 100°F for most units.

GAS VELOCITY

Exit velocity from the driers will be about 40 fps for controlled units. Other units are expected to have an exit velocity of 10 fps.

STACK HEIGHT

Stack heights for three plants ranged from 20 - 40 feet. Assume 30 feet when data are unavailable.

TABLE X-1.1

Exhaust Gases from Dry Cleaning Plants[3]

Exhaust Flow scfm	Exhaust Temp. °F	Stack Velocity fps	Stack Height	Operating Time	Control Equipment
8500	75		40	35 min./bat. 12 bat./wk.	Dilution
3000	110	40	25	8 hrs./bat. 5 bat./wk.	Carbon
3000	85		20	45 min./bat. 8 bat./wk.	--

CHAPTER X-2

SURFACE COATING OPERATION[A]

Surface coating operations cover a myriad of industrial applications ranging from the spray painting of automobiles to the lithographing of food cans. Most fabricating plants which manufacture a finished product will have a surface coating operation.

Basic coating operations consist of dipping, spraying or flow coating.[4] Combinations of these operations are likely. Spraying is probably used more than dipping or flow coating simply because of the economics of the materials used. All spraying operations are vented to prevent buildup of the paint odors. The principal air contaminants are particulate matter, consisting of fine paint particles and solvent vapors.[5] Dipping and flow coating operations are seldom vented or controlled. The principal air contaminant from these operations is solvent vapors.

Particulate air pollutants can be controlled by baffle plates, filters and water spray curtains. Organic vapors are controlled by thermal or catalytic incineration.[6,7]

Operational times vary with the industrial applications. Spray painting of automobiles would be expected to operate continuously 24 hours/day and 5 days a week. Painting of steel drums may operate 1 shift per day and 5 days a week.

GAS FLOW RATE

Exhaust gas flow rate in the case of spray painting is dependent on the size opening of the spray booth and on a minimum indraft velocity of about 100 fpm. Larger areas would, of course, require more gas flow. Table X-2.1 summarizes data from several kinds of surface coating operations.[3] Exhaust flow rates ranged from 600 to 60,000 scfm, but most vented areas run about 12,000 cfm (Figure X-2.1). Operations using thermal incinerators generally operate at 5,000 scfm or below because of the cost of fuel and the desire to have high concentrations of vapors.

GAS TEMPERATURE

Exhaust gas temperatures for operations without incinerators are ambient, so assume 60°F. Gas exit temperatures for those operations with incinerators ranged from 400 - 1000°F for six units. Assume 700°F.

GAS VELOCITY

Gas exit velocities from over 20 data observations ranged from 5 to 63 fps with a mean of about 40 fps. It should be noted that one industrial plant may have many stacks for surface coating ventilation. One site visit revealed about 20 stacks from an auto assembly plant.[7]

STACK HEIGHT

The stack heights ranged from 0 to 75 feet. Surface coating vent stacks are usually located on the top of the plant and protrude about 10 feet. The stacks are almost all made of sheet steel and are about 15 inches in diameter. When no stack height data are available, assume 50 feet for modeling.

TABLE X-2.1

Exhaust Gases from Surface Coating Operations[6,7]

Production Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Stack Velocity fps	Stack Height ft.	Operating Times
Auto Painting	360	12.0	Ambient	28	47	8 hr./day 5 day/wk.
	36	10.0	Ambient	45	58	8 hr./day 5 day/wk.
	36	12.0	Ambient	46	47	8 hr./day 5 day/wk.
Paint Oven	1,000	12.0	285	42	60	16 hr./day 5 day/wk.
Metal Sanding	2,360	0.60	Ambient	5	0	8 hr./day 5 day/wk.
Auto Paint	32	9.6	Ambient	37	37	14 hr./day 5 day/wk.
Manufacturing Steel Drums	50	18.2	Ambient	9	25	2 hr./day 5 day/wk.
Auto Paint	100	60.0	100	63	28	4 min./bat. 32 bat./day
	63	38.0	70	44	36	16 hr./day 5 day/wk.
	63	47.5	70	42	40	20 hr./day 6 day/wk.

TABLE X-2.1

Exhaust Gases from Surface Coating Operations (cont'd)

Production Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. ^{o}F	Stack Velocity fps	Stack Height ft.	Operating Times
Auto Paint	520	50.0	70	38	38	16 hr./day 5 day/wk.
	1,380	50.0	70	38	38	16 hr./day 5 day/wk.
Baking Plant	156	4.2	300	38	38	16 hr./day 5 day/wk.
Litho Ovens	-	34.0	450	25	75	8 hr./day 5 day/wk.
		6.0	1,000	50	70	8 hr./day 5 day/wk.
		6.0	1,000	50	70	8 hr./day 5 day/wk.
Gravure Printing Surface Coating Oper.	-	60.0	85 - 90	56	32	
Manufacture of Steel Drums						
Hot Spray	100	18.6	Ambient	55	20	
Hot Spray	30	3.5	Ambient	22	30	
Paint Spray	3	1.0	Ambient	8	30	
Hot Spray	120	18.6	Ambient	55	25	

TABLE X-2.1

Exhaust Gases from Surface Coating Operations (cont'd)

Production Operation	Input Rate lb./hr.	Exhaust Flow 1000 scfm	Exhaust Temp. °F	Stack Velocity fps	Stack Height ft.	Operating Times
Can Paint Baking Oven	258	20.0	400	60	60	
Enamel Spray	43	37.5	70		60	
Aluminum Can Spraying	2.1	3.2	80	36	39	
	8.34	3.1	200	30	39	
	0.21	0.5	80	22	39	
Aluminum Can Bake Oven	13.37	2.0	230	33	39	
Chrome Plating		9.0	80	43	20.75	

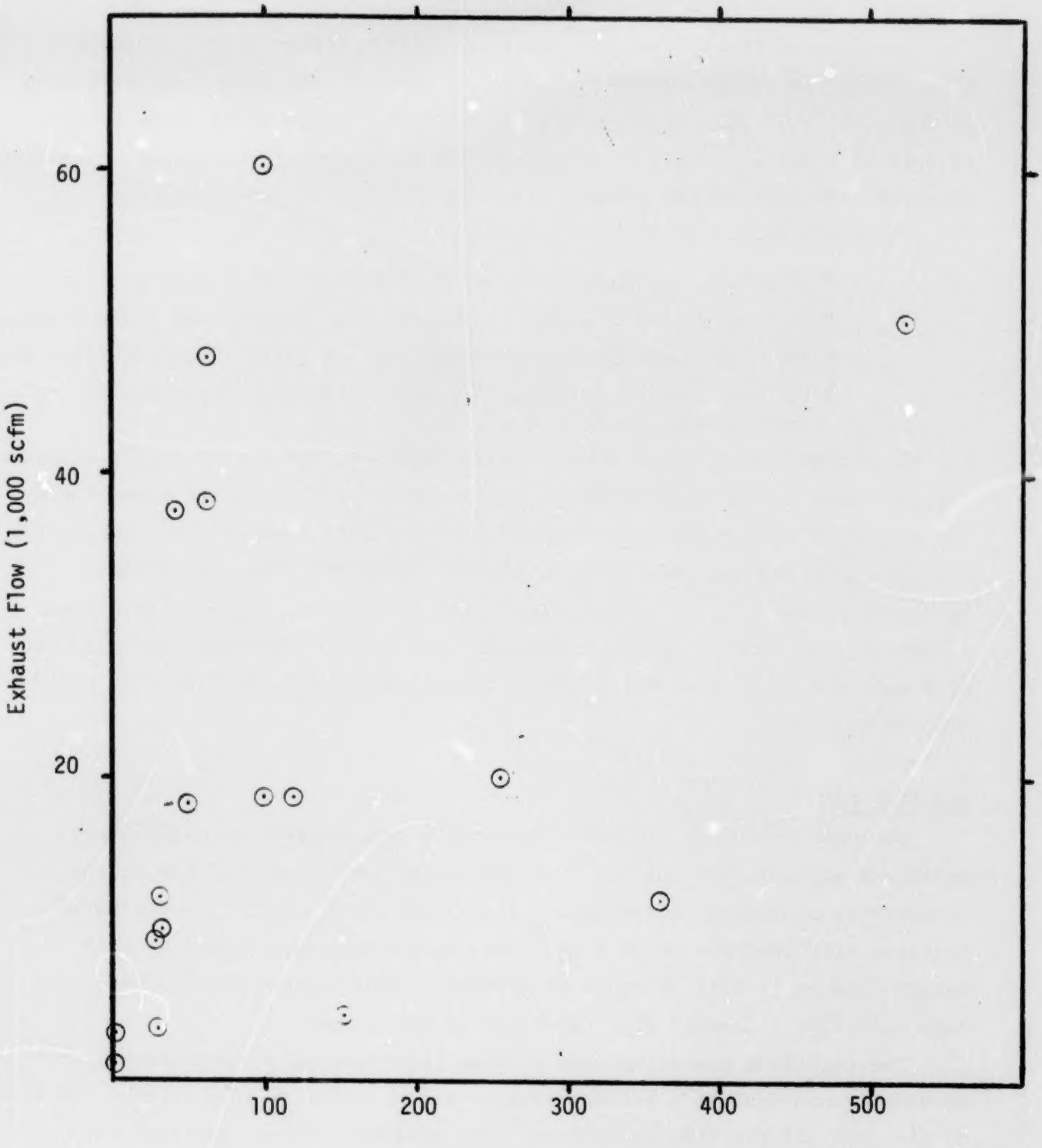


Figure X-2.1 Exhaust flow rates for surface coating operations

CHAPTER X-3

GASOLINE MARKETING [D]

Gasoline marketing requires several transfer phases to get gasoline from refineries to the carburetor of an automobile. Every metropolitan area of the U. S. will have several clusters of bulk storage tanks (tank farms) as part of a large distribution network for the major oil companies. Gasoline is moved from here to the service stations by truck as needs demand.

The major points of emission include:

- Breathing and working losses from bulk terminal storage tanks.
- Filling losses from bulk terminals tank filling and truck loading.
- Filling losses from underground storage tanks at service stations.
- Filling losses (and spillage) from automobile tank filling at service stations.[8]

Air contaminants associated with gasoline marketing are simply gasoline vapors expelled from a tank by displacement as a result of the filling operation.[9] The only type of air pollution control utilized is a vapor return system; i.e. a return line deliver the vapors to the master vessel while unloading. Return lines are popular in California,but, at present, are not being used elsewhere in the U. S. Service stations have a vent pipe about 10 to 20 feet high made out of 2" pipe which carrys the vapors away to be dispersed into the atmosphere.

GAS FLOW RATE

American Petroleum Institute nomographs may be used for calculating emissions and exit gas volumes from petroleum storage tanks. Figure X-3.1 illustrates breathing losses from a fixed roof tank.[5] Since one gallon of gasoline will vaporize to 29.6 $ft.^3$, one barrel of liquid gasoline will occupy 1240 cubic feet of space as a vapor.[5] Thus, by knowing the breathing loss in bbl/yr., exhaust flow rates can be calculated.

The exit flow resulting from filling bulk terminals, tank trucks, or an underground tank at a service station can be calculated by knowing the size of the tank and the time to fill it.[10] One gallon of liquid gasoline will occupy 0.133 $ft.^3$ of space (7.5 gallon equals 1 cubic foot). Therefore, if a bulk tank service station had a capacity of 2,000 gal. and was filled in 20 minutes, the flow rate could be calculated as 13.3 scfm. An average

15 gallons of gas is pumped into a car during a filling operation which takes about 5 minutes. The gas flow rate from this operation would be 0.5 scfm.

GAS TEMPERATURE

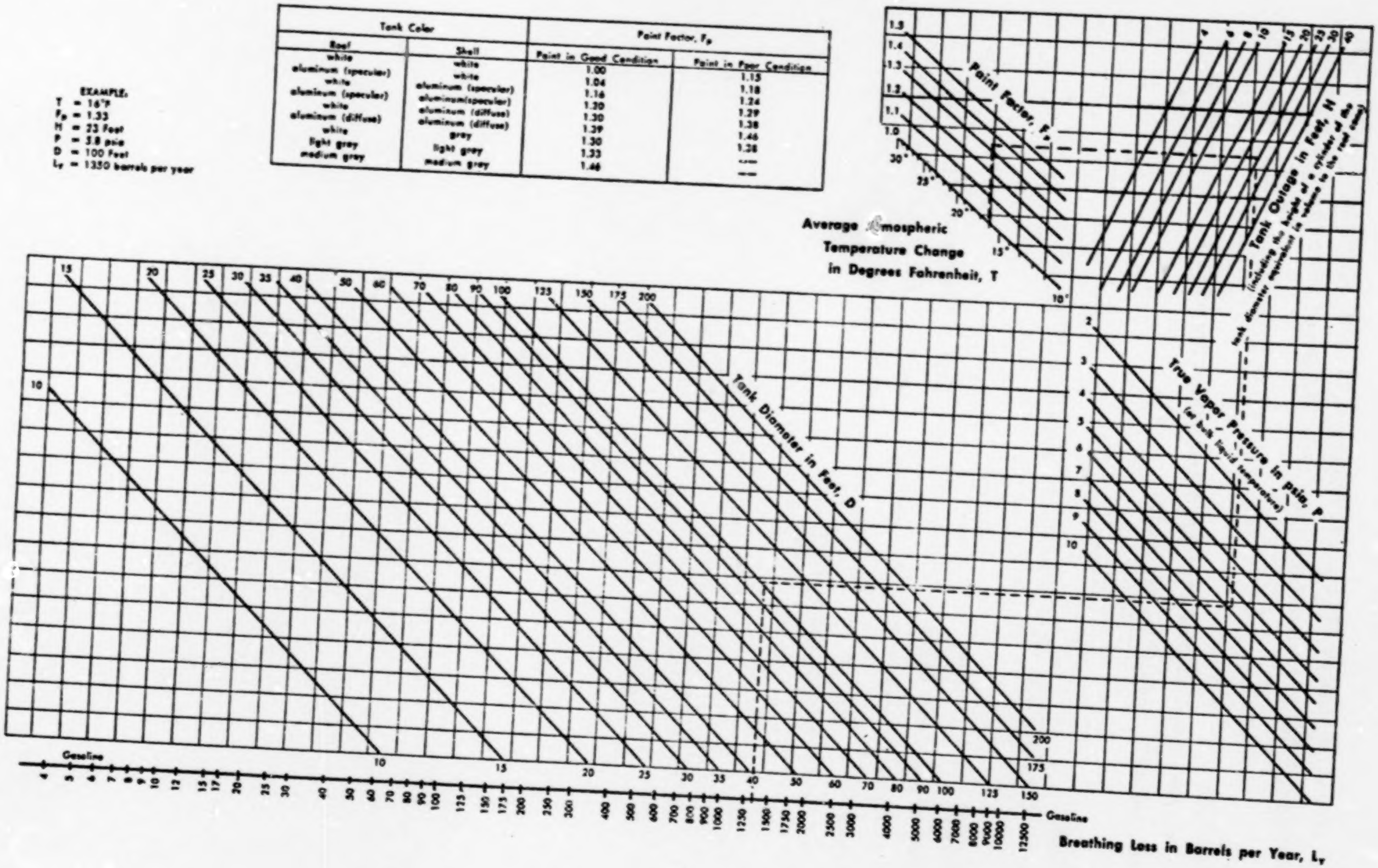
Exhaust gas temperatures from gasoline marketing will be near ambient conditions, so 60°F should be assumed.

GAS VELOCITY

Gas exit velocities will usually be less than 5 fps.

STACK HEIGHT

Gasoline storage tanks are about 50 feet high. The vent pipe at a service station is about 10 - 20 feet high. However, gasoline marketing sources should be treated as an area source for modeling because of the number and scale of the operations.



EXAMPLE:
T = 16°F
F_p = 1.33
H = 23 Feet
P = 3.8 psia
D = 100 Feet
L_Y = 1350 barrels per year

Tank Color		Paint Factor, F_p	
Roof	Shell	Paint in Good Condition	Paint in Poor Condition
white	white	1.00	1.15
aluminum (specular)	white	1.04	1.18
white	aluminum (specular)	1.16	1.24
aluminum (specular)	aluminum (specular)	1.20	1.29
white	aluminum (diffuse)	1.30	1.38
aluminum (diffuse)	aluminum (diffuse)	1.39	1.46
white	gray	1.30	1.28
light grey	light grey	1.33	—
medium grey	medium grey	1.46	—

Figure X-3.1 Breathing emissions of gasoline and crude oil from fixed-roof tanks (American Petroleum Institute, 1962a).

CHAPTER X REFERENCES

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APPENDIX A

Theoretical Exhaust Flow Rate and Velocities

Flow Rate

Often more precise flow rates will be needed to evaluate a specific combustion source. This part of the appendix will show the reader how to calculate the exhaust flow rates when data on coal analyses and excess air rates are known. The theoretical procedure is taken from Combustion Engineering (New York, N.Y.) one of several published sources which have similar calculation procedures. The following example is for bituminous coal combustion.

Given:

Coal Analysis element	% weight composition
C	63.5
H_2	4.0
O_2	7.5
S	1.5
N	1.3
Moisture	15.0
Ash	7.2

Higher heating value is 11,350 BTU/lb.

Excess air rate is 20%

A factor, VM, is calculated, then used with Figure A-1 to determine the amount of air needed for combustion.

$$VM = \frac{C}{H_2 + 0.1\ O_2} = \frac{63.5}{4.0 + 0.1\ (7.5)} = 13.2$$

With an excess air rate of 20% and VM = 13.2, read the atmospheric air requirement of 940 pounds of air per million BTU input. The density of air is 0.0750 lb./ft.^{3} at 70°F, 1 atm. The amount of combustion air needed to burn 10 tons per hour of coal being fed to the boiler is

$$\text{Combustion} = \frac{10\ \text{tons}}{\text{hr.}}\ \frac{\text{hrs.}}{60\ \text{min.}}\ \frac{2000\ \text{lbs}}{\text{ton}}\ \frac{11{,}350\ \text{BTU}}{\text{lb.}}\ \frac{940\ \text{lb. air}}{10^6\ \text{BTU}}\ \frac{\text{ft}^3}{0.0750\ \text{lb. air}}$$

$$= 47{,}000\ \text{scfm}$$

The exhaust flow rate from this source is 1.05 times the combustion air or:

Exhaust Flow Rate (scfm) = 49,000 scfm

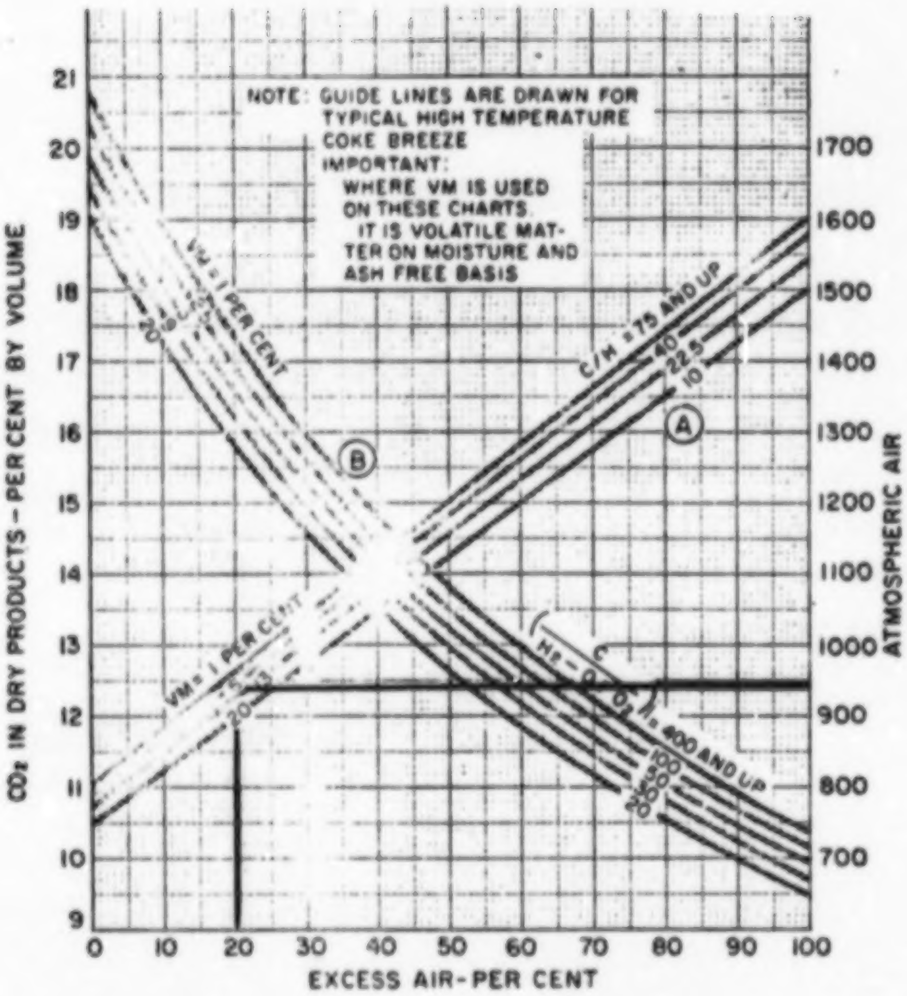

Figure A-1 Theoretical Air Requirements for Bituminous Coal Combustion.

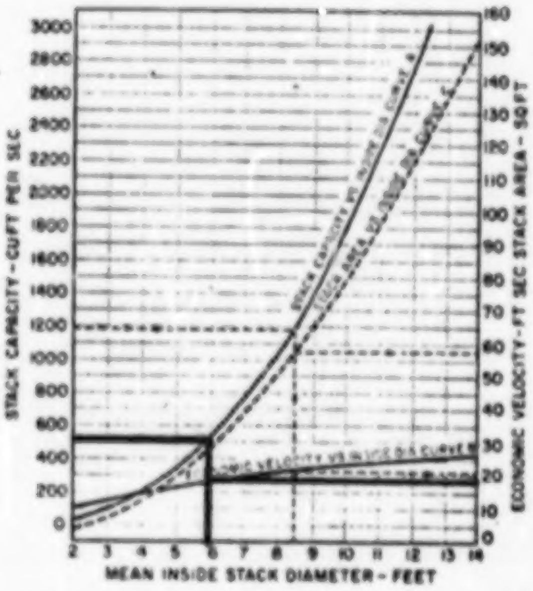

Figure A-2 Theoretical Gas Exit Velocity - Stack Capacity (cuft per sec.) vs mean inside stack diameter (feet).

Velocity

Often, throughout this report, data were available on stack flow rate, but no data were listed for gas exit velocity. With the use of Figure A-2, Combustion Engineering, the reader can also determine economic stack exit velocity. For example, if the flow rate for a sulfuric acid plant was 30,000 scfm (500 scfs) the stack diameter can be read from Figure A-2 of 5.9 feet. The area of the stack can be calculated which is then used to calculate the velocity, or Figure A-2 can be read directly.

$$\text{Calculated Gas Exit Velocity (fps)} = \frac{\text{Flow Rate}}{\text{Area of stack}}$$

$$= \frac{500 \text{ ft.}^3/\text{sec.}}{\frac{(5.9)^2}{4} \text{ ft.}^2}$$

$$= 18.2 \text{ fps}$$